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Development of Composite Components for the CCN-150-5C Transfer Pump

H. K. Telegadas
and
George F. Wilhelmi

Carderock Division
Naval Surface Warfare Center
Bethesda, MD 20084-5000

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United States Coast Guard
Research and Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

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Marc B. Mandler
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

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The R&D Center's technical point of contact is Kenneth Bitting, 860-441-2733.

16. Abstract

The development of a composite suction bell and pump bowl for the Coast Guard's CCN-150-5C cargo transfer pump is reported. The effort was undertaken in order to determine the feasibility of using composite components to reduce the weight of this pump. The reduction in weight could benefit the Coast Guard's Strike Teams by increasing deployment proficiency and decreasing personnel injury. First, an all stainless steel CCN-150-5C was tested at the Atlantic Strike Team's test facility at Ft. Dix, New Jersey. The tests conducted showed that the CCN-150-5C did not experience large loads during normal operation. Next, a composite suction bell and pump bowl were designed to retrofit into an existing CCN-150-5C. The parts were fabricated and the partially composite CCN-150-5C assembled. Subsequent testing of this pump showed that the composite parts performed as well as their metallic counterparts. Overall, the pump's weight was reduced from 199 pounds to 143 pounds, a 28% reduction. Several options for future work are outlined at the end of the report. The final recommendation is that a joint Navy and Coast Guard cargo transfer pump be designed, from the ground up, making extensive use of composite materials early in the design stage in order to realize full potential benefits.

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METRIC CONVERSION FACTORS

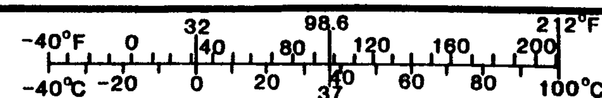
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ADMINISTRATIVE INFORMATION

This research and development effort was sponsored by the U.S. Coast Guard R&D Center, Groton, CT., and directed by LT. Michael J. Roer and LTJG. Dan Frank of the Marine Environmental Safety Branch. Work was executed under sponsor order No. Z51100-3-E00608, Work Unit 1-2723-900, DN 502519.

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EXECUTIVE SUMMARY

Objective

The objective of this study was to determine the feasibility of using composite materials to reduce the weight of the National Strike Force cargo transfer pumps.

Technical Approach

All the pumps in the Coast Guard's inventory were investigated. The study eventually focused on the CCN-150 transfer pump.

In phase one of the project, this pump was tested at a variety of operating conditions to determine the operational strain levels within the pump. The results of these tests may be found in CG-D-10-97.

In phase two of the project, a composite pump bowl and suction bell were designed and fitted to the existing CCN-150. Subsequent tests showed that the composite parts performed as well as their metallic counterparts. The results of these tests may be found in CG-D-11-97.

Findings

Tests showed that the performance of the pump was not degraded with the composite parts. The use of the composite material reduced the weight of the stainless steel pump by 28%.

Recommendations

The report offers three options for future pump development: a) perform additional testing to refine the current composite suction bell and pump bowl, b) fabricate additional parts of composite to reduce weight further, and c) design an all new joint Navy/Coast Guard transfer pump that would minimize weight and optimize the strength advantages of composites.

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INTRODUCTION

The primary purpose of the Coast Guard's National Strike Force Teams is to rapidly deploy in response to oil and chemical spill incidents in order to minimize the adverse impact to the public and environment. The teams carryout this purpose by maintaining an inventory of highly specialized response equipment. Included in this equipment is an inventory of submersible pumping systems used to offload cargo from stranded tank vessels. Design operations precept is "lightweight, air transportable", but these pumps require weight handling equipment at every point of transportation from the NSF depot to the spill site. Pumps are often moved and installed "by hand" requiring a number of personnel. Because the pumps and handling equipment is heavy and cumbersome, delays in deployment and injury to personnel may occur. In particular, the submersible pumps themselves are quite heavy with older units weighing upwards of 500 pounds. It would seem reasonable that the strike teams could benefit from lighter transfer equipment if the reduction in weight did not diminish their ruggedness or pumping capacity.

The Coast Guard R&D Center assigned to the Naval Surface Warfare Center Carderock Division (NSWCCD) the task of investigating the feasibility of employing composite materials to reduce the weight of the submersible transfer pumps. The investigation quickly focused on one pump in particular, the CCN-150-5C. The CCN-150-5C is an all stainless steel mixed-flow submersible pump 28 inches long, 12 inches in diameter, and weighing 187 pounds. A photograph of the CCN-150-5C is shown in Fig. 1. The reasons for focusing on this pump is that the CCN-150-5C is one of the lightest and most versatile pumps in the Strike Force inventory and is currently the most modern pump in that inventory. The CCN-150-5C is fast becoming the favorite pump of Strike Force personnel.

A CCN-150-5C was obtained by NSWCCD and disassembled. A photograph and schematic of a disassembled CCN-150-5C is shown in Figs. 2 and 3 respectively. A list of each of the components and their respective weights is given in Table 1. An assessment of the feasibility of fabricating each part out of composite materials was completed. A summary report entitled *Feasibility of Using Composite Materials to Reduce the Weight of the CCN-150 Transfer Pump* was issued. [1] In that report, several options for fabricating a partially composite CCN-150-5C pump were outlined. The low risk option outlined in the report, which involves replacing the suction bell and pump bowl with composite parts, was chosen as the next logical endeavor. This report describes the effort undertaken to develop a composite suction bell and pump bowl for the CCN-150-5C transfer pump.

Table 1. Major Components of the CCN-150-5C.	
Pump Component	Wt. (lb)
motor housing	42.6
hydraulic motor	63.2
pump bowl	31.8
impeller	11.0
suction bell	46.2
strainer	4.6

HYDROMECHANICAL TEST: STEEL CCN-15-5C

TEST SET-UP

In order to rationally design composite components for the CCN-150-5C, NSWCCD attempted to obtain engineering drawings, physical loading conditions, and any other pertinent design information about the conventional CCN-150-5C. The only information obtained was an Operations and Maintenance Technical Manual. [2] The most relevant information found in the manual is the discharge pressure versus flow rate characteristics of the pump. Essentially, the pump's discharge pressure increases as flow rate decreases and reaches a maximum of 80 psi at zero flow rate. Because of the lack of design information, the Coast Guard and NSWCCD decided to attach strain gages at several structurally critical locations on the CCN-150-5C and measure the level of strain over a range of operating flow conditions from fully open to completely closed (dead-head condition).

Numerous strain gages were attached to the CCN-150-5C. A 0/45/90 strain gage rosette was attached at four equally spaced locations around the outside circumference of the suction bell, pump bowl, and motor housing. The individual gages of the rosette were aligned with the axis of the pump (axial direction), around the circumference of the pump (circumferential direction), and at 45° with respect to these two directions (45° direction). These locations and directions are shown schematically in Fig. 4. In addition, unidirectional gages were attached to the left, right, and back sides of the discharge tube. These three gages were aligned with the long axis of the pump, i.e., the axial direction. Finally, a 0/45/90 strain gage rosette was attached at three locations along two of the internal vanes of the pump bowl. The locations were at the tip, along the middle of the vane, and at the root of the vane. The three individual gages of the rosette were aligned with the radial direction, circumfential direction, and at 45° with respect to these two directions. A schematic of these locations and directions is shown in Fig. 5. A photograph of the instrumented pump bowl is shown in Fig. 6. The completely instrumented CCN-150-5C is shown in Fig. 7. A summary list of the strain gages and their respective designation numbers used for this test is given in Table 2.

Computer controlled data acquisition equipment was used to collect strain data at the required test conditions. The equipment included the Micro Measurements System 4000 data collection unit, a PC computer, printer, and line conditioner. A photograph of the system is shown in Fig. 8.

The instrumented pump and data collection equipment was shipped to the test facility at the Atlantic Strike Team (AST) headquarters at Ft. Dix, New Jersey. It was decided to run the tests at the AST for several reasons. First, the AST has a test tank suitable for running the CCN-150-5C. Second, all of the necessary auxiliary equipment needed to run the test, such as the prime mover, hydraulic lines, discharge hoses etc. would be on hand as needed. Finally, the Strike Team personnel trained in operating the equipment would also be on hand to help set-up and run the test and provide expertise in problem solving should any arise. A photograph of the test tank is shown in Fig. 9. The tank measures approximately 10 feet x 10 feet x 4 feet deep. The fluid used in this test facility is water.

A schematic of the test loop is shown in Fig. 10. The pump is driven by a diesel-engine prime mover. A photograph of the prime mover is shown in Fig. 11. A series of 6 inch hoses are connected to the pump so that the fluid flows from the pump, through a magnetic flow meter and ball valve, and finally back into the test tank. A photograph of the CCN-150-5C with the hydraulic and discharge lines attached is shown in Fig. 12. A photograph of the flow meter is shown in Fig. 13. The ball valve is used to throttle the flow so that the performance of the pump can be measured at a variety of flow conditions. A photograph of the valve is shown in Fig. 14. A number of small hoses are connected so that the suction, discharge , and differential pressures can be measured at the various flow conditions. A photograph of this equipment is shown in Fig. 15. Finally, the data acquisition equipment is housed in a NSF Mobile Command Unit in order to protect it from inclement weather. A photograph of the Mobile Command Unit is shown in Fig. 16.

The CCN-150-5C was lowered into the test tank and operated at four different flow conditions. The four conditions were fully open (condition A), completely closed (condition D), and two partially closed conditions (conditions B and C). As described above, the ball valve was used to throttle the flow. The conditions were not quantitatively decided upon but were obtained by having full flowing fluid for condition A, closing the valve slightly for condition B, closing it further for condition C, and finally stopping the flow in condition D. Due to severe weather, neither the equipment to measure pressure nor the magnetic flow meter were operational. However, because the strain gage instrumentation was housed in the Mobil Command Unit, the equipment was operational and strain readings were taken at all flow conditions. A photograph of the CCN-150-5C submerged in the test tank during operation is shown in Fig. 17.

Table 2. Summary of the strain gages used in the CCN-150-5C hydromechanical test.			
Component	No. Gages	Gage Type	Micromeasurements Designation
Suction Bell	4	0/45/90 rosette	CEA-06-250UR-350
Pump Bowl (outside ring)	4	0/45/90 rosette	CEA-06-250UR-120
Pump Bowl Vanes	3 ea. vane	0/45/90 rosette	CEA-06-250UR-120
Motor Housing	4	0/45/90 rosette	CEA-06-250UR-350
Discharge Tube	3	unidirectional	CEA-06-062UW-350

TEST RESULTS

At each of the four flow conditions discussed above, three separate strain readings were taken. The results discussed in this section is the average of the three separate readings. The average strains are summarized in table form in Appendix A. In the cases where 0/45/90 strain gage rosettes were used, the principal strains and stresses are also reported. The equations needed to calculate the principal stresses and strains at a point based on data collected with a 0/45/90 rosette are well known. [3] In order to perform those calculations, each pump component was assumed to have a modulus of $30x10^6$ psi and a Poisson's Ratio of 0.3. In the case of the discharge tube, where a single unidirectional gage was used, only the unidirectional strain levels are reported.

Suction Bell

Overall, the level of strain, and subsequently the stress, in the suction bell are quite low. Several observations can be made. First, the loading on the suction bell, for all intents and purposes, is axisymmetric. Even though one of the gages was not operational, the level of strain at each of the other three gages around the circumference is essentially equal. This is true at all four flow conditions. Second, the level of strain increases as the flow becomes more constricted. The maximum strain level is reached at the dead head condition. At this condition, the maximum stress in the suction bell is about 2.5 ksi. Third, the strain in the circumferential direction is always the greatest as compared to either the axial or 45^o directions. Finally, the principle strains are tensile for all flow conditions. These lead to the conclusion that the primary load induced to this part during operation is internal pressure.

Pump Bowl

The strains and stresses measured on the outside ring of the pump bowl were also quite low. The same sort of trends noticed for the suction bell were observed for this component, that is:

1. The strains were essentially equal around the circumference of the pump bowl indicating axisymmetric loading.

2. The level of strain increases with decreasing flow rate and reaches a maximum at the dead head condition due to increasing back pressure. The maximum stress at this point is about 1.5 ksi.

3. The circumferential strain is always the greatest.

4. The principal strains are always positive.

Prior to this testing, it was thought that the primary loading on this part might be torque due to the pump bowl's vanes recovering flow imparted by the impeller. If this were true, the level of strain in the 45^{o} direction would have been greater than the other two directions. However, it would seem that the primary loading condition imparted to this part during operation is also internal pressure.

Motor Housing

The same sorts of observations found for the suction bell and pump bowl can be made for the motor housing. The strains are axisymmetric, increasing with decreasing flow rate, and are always positive with the circumferential strain always highest. However, the strains and stresses in the motor housing are larger than those in either the suction bell or pump bowl, the maximum stress being about 4.2 ksi. It would seem that internal pressure is also the primary load for this pump component.

Pump Bowl Vanes

Both pump bowl vanes have very similar responses. This indicates that the pressure loading along each of the five blades is equal. The highest stresses are measured at the tip of the blades during the dead head condition. The maximum stress calculated is 2.6 ksi for blade no. 1 and 2.2 ksi for blade no. 2. Some other observations are that the strains increase as the flow becomes impeded, that the radial strains tend to be the highest in all flow cases, and that the magnitude of stress decreases from the tip to the root (this trend comes as no surprise because the thickness of the blades increases from tip to root). Finally, a compressive strain and stress is observed for both blades in the middle location. The maximum compressive stress is -2.0 ksi for blade no. 1 and -1.5 ksi for blade no. 2. It is interesting to note that this compressive stress is essentially independent of flow condition, that is, the magnitude of this stress component did not change with changing flow condition.

The pressure distribution is probably quite complicated along each of these blades. No attempt was made, at this time, to quantify this pressure distribution. The strain readings are used to calculate the magnitude of stress in each of the blades and determine its severity.

Discharge Tube

In addition to the four flow conditions, strain readings were taken when the CCN-150-5C pump was hanging by the discharge hose only. In this state the rigging lines were not attached. It was thought that at some time the pump might be handled by the hose only and an idea of the magnitude of load imparted to the tube under this condition was deemed important. The axial strain recorded on the left and right side

of the discharge tube, hanging by the hose only, were essentially identical and equal to about 13.5 $\mu\varepsilon$. However, on the back side of the tube, the strain was compressive and equal to about -15.0 $\mu\varepsilon$. Obviously the loading is not axisymmetric and a bending moment is imparted to the discharge tube. The rigging lines were then attached, the pump lowered into the tank, and the flow tests performed. Throughout the tests, the loading remained nonaxisymmetric with tensile strains on the left and right sides of the discharge tube and compressive strain on the back. The strains increased with decreasing flow. The maximum strains recorded (at the dead head condition) were about 75 $\mu\varepsilon$ on the left and right sides and -25 $\mu\varepsilon$ on the back side.

DISCUSSION

An attempt to completely characterize and quantify the loads imparted to the CCN-150-5C during normal operation was not the purpose of this testing. The purpose was to obtain the level of strains in the individual pump components during operation and to determine if those strains (and resulting stresses) were severe enough to warrant a more detailed analysis of the pump. Overall, the strains and resulting stresses in the components of the CCN-150-5C during normal flow conditions are small. In particular, the strains and stresses imparted to the suction bell and pump bowl, assuming a minimal yield strength for stainless steel of 40,000 psi, result in a ratio of yield stress to operational stress of 16:1. Thus, the loads imparted to the CCN-150-5C during normal operation appear to be minimal. At this time it was decided to design and fabricate a composite pump bowl and suction bell on a one-to-one basis with their corresponding metallic version, that is, the components would be essentially replicated. The remainder of this report details the process of developing those composite components and describes the testing performed in order to verify their structural integrity.

COMPOSITE PUMP COMPONENTS

SUCTION BELL

A photograph of the suction bell is shown in Figs. 18 and 19. The inlet side of the suction bell is stiffened with a set of three radial ribs onto which a set of three chopping blades are attached. The strainer attaches to the suction bell at the inlet side. The suction bell is then attached to the motor housing with bolts that pass through the outer ring of the pump bowl and sandwich it between the suction bell and motor housing. A clear picture of this assembly is shown in the schematic, Fig. 3. Since engineering drawings of the suction bell were not obtained, it was given to the Design and Engineering Support Group at NSWCCD. The Design and Engineering Support Group was then able to produce a complete engineering drawing of the suction bell. A copy of the drawing is included in the feasibility report. [4]

Any composite replication of the suction bell must have several important features. First, the bolt circles for attaching the strainer and motor housing must line up exactly, for obvious reasons. Second, the inner profile of the suction bell must be

replicated exactly so that the flow into the pump will not be changed, potentially reducing the efficiency of the pump, and so that the impeller does not interfere with the suction bell during operation. A detailed table of the inside profile is given in Appendix B. The outside profile of the pump is not critical other than the requirement that the outside diameter remain less that 12.25 inches at any location.

The material requirements for this application are not too severe. The finished part should be able to withstand temperature excursion from 0^oF to about 150^oF without loss of mechanical properties. A toughened, thermosetting resin (either epoxy or vinyl ester) is recommended. This class of resins have quite good mechanical properties without being expensive. The resin must have some toughening (usually introduced by the addition of rubber into the resin) in order to withstand handling impacts. Finally, glass fibers in lieu of carbon fibers are recommended. This application did not seem to warrant the higher mechanical properties of carbon fibers, nor the added expense. Appendix C contains a copy of the statement of work outlining the geometric and material requirements.

The composite suction bell was procured under competitive procurement. Three vendors were approached about fabricating a composite suction bell. Each was given an opportunity to inspect the metallic suction bell, take measurements, and devise a fabrication plan. Two of the vendors responded with bids. The procurement was awarded to the Prosser Company which submitted the least expensive bid. Their cost for fabricating two composite suction bells was $4560.00.

The Prosser Company chose to fabricate the suction bell via hand lay-up on a male mold. A photograph of the mold (in pieces) is shown in Fig. 20. The assembled mold is shown in Fig. 21. The mold is split at the point where the inner profile reaches a minimum diameter so that after fabrication, the mold can be removed from both ends. The resin chosen for this application was Dow 8084 Derakane vinyl ester . The lay-up consisted of an initial layer of c-veil E-glass mat so that the inside of the suction bell would have a smooth, resin-rich layer. Alternating layers of 2 ounce E-glass chopped mat and 24 ounce E-glass woven roving were then applied until the desired wall thickness was achieved. Some of these constituent materials are shown in Fig. 22. The ribs were fabricated separately and attached with secondary bonds. The entire piece was then machined to final dimensions. A series of photographs showing some of the processing steps are shown in Figs. 23-28. A photograph of the finished part is shown by itself in Fig. 29 and next to its metallic counterpart in Fig. 30. The composite suction bell weighs 12.8 pounds, a weight saving of 72%.

PUMP BOWL

A photograph of the pump bowl is shown in Fig. 31. and 32. The pump bowl consists of a center hub, five vanes, and an outer ring. It is assembled into the pump between the suction bell and motor housing with bolts that pass from the suction bell, through holes in the outer ring, into the motor housing. The five vanes act to recover

flow as it leaves the impeller, located immediately upstream from the pump bowl. The assembly is shown clearly in the schematic, Fig. 3.

Due to the complex geometry of the pump bowl and to the fact that only a limited number is required (essentially one, a prototype), machining is the preferred method of fabrication for this part. The cost of machining a pump bowl, as compared to molding one, is much less because an initial investment of time and money in designing and building a mold is avoided. It is also felt that a higher quality part can be made by machining a pump bowl. The tolerances needed in order to fit this part with the other pump components are probably easier to obtain via machining. Also variations in material properties from place to place, that sometimes occur in molding due to melt flow, is avoided.

The material requirements for this part are similar to those of the suction bell. The part should be made of a structural composite consisting of glass fibers in an epoxy or vinyl ester resin. The resin, however, does not need to be toughened, per se, because the pump bowl is essentially contained within the pump itself. An important requirement is that the composite used to fabricate this part should have excellent resistance to erosion, recirculation, and potential cavitation, conditions that are likely to occur directly downstream from the impeller. The material should also be easily machined without introducing flaws such as delaminations.

A sole source contract was issued to the Sims Pump and Valve Company to fabricate two composite pump bowls from their proprietary Simsite 375 material. The contract was issued for several reasons. First, the Sims Company has been fabricating machinery and pump components from their Simsite composite materials since 1955. [5] In particular, Sims has been fabricating composite pump impellers by machining them out of thick blocks of their Simsite materials. Many of these impellers have very complex geometries, even more so than the CCN-150-5C's pump bowl. The conclusion is that the Sims Company has the experience and expertise required for machining a quality composite pump bowl. Second, the Navy has been using replacement Simsite impellers in a variety of pumps since the late 1960's. [6] This long term, positive experience led to detailed material property investigations on the wear and structural characteristics of Simsite composites. [7,8] The Simsite materials, especially Simsite 375, appear to have the erosion, cavitation, and mechanical properties needed for this application. A copy of the rational for purchasining composite pump bowls from the Sims Pump Valve Company is included in Appendix D. The total cost for two composite pump bowls is $19,500.00.

The metallic pump bowl from the CCN-150-5C was sent to the Sims Pump and Valve Company. Sims was then able to obtain the direct measurement needed for machining. The pump bowl was fabricated in two parts. The Hub and vanes were machined from a single thick block of Simsite 375. The outer ring was machined out of Simsite 375 separately and attached with both pins and adhesive to the sides of the vanes. The pump bowl was replicated exactly except for two small modifications. First, the thickness of the ring was increased by increasing the outer diameter by 1/4 inch and decreasing the inner diameter by 1/4 inch. This was done in order to

provide more material surrounding the bolts used to install the pump bowl. Second, the individual vanes were thickened slightly (approximately 1/8 inch) in order to provide geometric stiffening to the vanes since Simsite 375 is a more compliant material than steel. These minor modifications were done at the recommendation of the Sims Company based on their first-hand experience. The finished composite pump bowl is shown in Fig. 33. It is also showed side-by-side with its metallic counterpart in Fig. 34. The composite pump bowl weighs 9.6 pounds which translates to a 70% weight reduction.

HYDROMECHANICAL TEST: PARTIALLY COMPOSITE CCN-150-5C

TEST SET-UP

An obvious question is: Do the composite pump bowl and suction bell affect the performance of the CCN-150-5C? In order to answer this question, it was decided to return to the test facility at Ft. Dix, New Jersey and carry out a series of tests comparing the performance of an all stainless steel CCN-150-5C with that of the compositized CCN-150-5C. The test would essentially compare the discharge pressure versus flow rate of each of the pumps. Recall, that this information was not obtained for an all stainless steel pump during the initial tests because of inclement weather. Because of the low strain levels recorded during the initial series of tests, it was decided not to strain gage either the all stainless steel nor compositized CCN-150-5C. The focus, this time, would be on the hydrodynamic performance only.

The CCN-150-5C at NSWCCD was put together with the composite parts. A photograph of the assembled compositized CCN-150-5C is shown by itself in Fig. 35 and next to an all stainless steel CCN-150-5C in Fig. 36. One modification was made during the assembling. A thicker gasket than normal was installed between the motor housing and pump bowl and between the pump bowl and suction bell. This modification has the effect of backing the impeller away from the suction bell, i.e., increasing the clearance between the impeller blades and inner wall of the suction bell. The increase in clearance was a precautionary measure taken to prevent the impeller from possibly rubbing against the suction bell during operation. Once the pump is in operation, the pressure differential across the blades of the impeller tries to pull it towards the inlet side of the pump, i.e., closer to the suction bell. The relative displacement of the impeller to the suction bell may be greater with the compositized CCN-150-5C than with the original steel pump because the composite materials used in this application are more compliant than steel. It is hoped that the increase in clearance between the impeller and suction bell, as a result of installing thicker gaskets, will make up for the possible increase in relative motion. The clearance between the impeller blades (four blades) and the inner wall of the suction bell for both the original thin gasket and the new thicker gasket are listed in Table 3. The clearance was measured at three locations along the edge of the blades. The average clearance between the impeller blades and the suction bell is 0.015 inches for

the all stainless steel CCN-150-5C and 0.028 inches for the compositized CCN-150-5C.

The test loop used in the original tests, shown schematically in Fig. 10, was recreated for this series of tests with two exceptions. First, no strain gage equipment was used. Second, a Blacett Incorporated flow meter, Model no. W1160 was substituted for the magnetic flow meter shown in Fig. 10. A photograph of this meter is shown in Fig. 37. The rest of the equipment and set-up remained the same.

Four tests were completed in order to determine if the composite parts degraded the performance of the CCN-150-5C transfer pump. First, an all stainless steel CCN-150-5C was operated at a variety of flow conditions from fully open to completely closed. During the test, the suction, discharge, and differential pressures were measured. Since the test tank is shallow, the suction pressure, for all intents and purposes, was zero during this and all subsequent tests. Therefore, only the discharge pressure is reported in the Test Results section below. This first test, labeled Run A, represents a baseline from which all other tests are compared. Next the test was repeated and labeled Run B. In the third test, Run C, both the pump and prime were replaced with different ones from the Atlantic Strike Team's inventory. Again, the pump was an all stainless steel CCN-150-5C. Both Run B and Run C were performed in order to establish the repeatability of the test method and determine the amount of variability in performance due to changing pumps and prime movers only. Thus a true assessment of the performance of the composite CCN-150-5C could be ascertained. Finally, in Run D, the partially composite CCN-150-5C was tested with the prime mover used in Run C. The pump was operated at a variety of flow conditions from fully open to completely closed. A summary of the four tests is given in Table 4. The hydraulic supply conditions for the four tests is also included in the table.

Table 3. Impeller / suction bell clearance measurements.

Location Along Blade	Blade No. 1	Blade No. 2	Blade No. 3	Blade No. 4
(All stainless steel CCN-150-5C w/ original gaskets.)				
1	0.009	0.009	0.013	0.019
2	0.010	0.012	0.017	0.022
3	0.010	0.012	0.018	0.021
Average:	0.010	0.011	0.016	0.021
(Compositized CCN-150-5C w/ new, thicker gaskets.)				
1	0.010	0.025	0.013	0.010
2	0.025	0.033	0.045	0.033
3	0.039	0.033	0.045	0.028
Average:	0.025	0.030	0.034	0.024

Table 4. Summary of performance tests.

Hydraulic Supply Conditions

Supply Pressure:	1700-2000 psig	Engine RPM:	2350
Return Pressure:	150 psig	Oil Temperature:	85-95 °F

Test Run	Pump (USCG Stencil No.)	Prime Mover (USCG Stencil No.)	Reason
A	USCG-PM-049	USCG PM-073	baseline
B	USCG-PM-049	USCG PM-073	repeatability
C	no stencil no.	USCG PM-070	repeatability
D	composite CCN-150-5C	USCG PM-070	performance appraisal

TEST RESULTS

The results are presented in table form in Appendix E. The discussion in this section focuses on the graphical form of the results, Figs 38-40.

The discharge pressure versus flow rate for the all stainless steel CCN-150-5C, Run A, is compared to the repeat of that identical test, Run B, in Fig. 38. The average difference between the two curves is 7.7%. The difference becomes maximum at higher flow rates. From this initial set of tests we conclude that the repeatability of our test method is on the order of 7-8 %.

When a different stainless steel pump and primer mover was tested and compared to the baseline test, the average difference over the test range was 6.7%. The two curves are compared in Fig. 39. The difference is on the same order as the repeatability found in the initial tests. From this experiment we conclude that different pumps and/or prime movers have essentially identical characteristics. When testing the compositized CCN-150-5C, any deviation from the baseline test greater than 7-8% will be attributed to the composite components themselves.

Finally, the results from the flow test with the compositized CCN-150-5C and the baseline test are compared in Fig. 40. The average difference between the two curves is 4.6%. The difference is greatest at the low flow rate/high pressure end of the curve. The drop off in performance at this extreme condition is thought to be the result of the larger-than-normal gap between the impeller and inner wall of the suction bell due to the use of thicker-than-normal replacement gaskets (refer to Table 3). It is thought that at the high pressure there may be some leaking of fluid past the edge of the impeller resulting in a decrease in efficiency. Even so, the difference is on the order of the repeatability of the test itself and the conclusion is that the composite pump components do not degrade the performance of the CCN-150-5C.

DISCUSSION

The four tests described above are by no means the end-all testing that could be performed on the partially composite CCN-150-5C. Several other tests that should be performed include:

- Further hydromechanical testing, similar to the tests described above, in order to verify the endurance of the composite components over time.
- Further hydromechanical testing, with the original gaskets, in order to verify that the replacement gaskets were the cause of the decrease in performance observed at the extreme high pressure condition.
- Further hydromechanical testing with other, more realistic fluids typically encountered during Strike Force Team operations.
- Mechanical impact testing of the composite parts in order to determine their ruggedness.

Even though more testing is required before the compositized CCN-150-5C can be used directly in service, the results to-date are extremely encouraging. For all intents and purposes, the conclusion is that the composite parts did not degrade the performance of the CCN-150-5C during this set of controlled tests. The composite parts fabricated and tested demonstrated that the weight of the CCN-150-5C could be reduced significantly without sacrifice to the hydromechanical performance. The overall weight of the CCN-150-5C was reduced from 199.4 pounds to 143.8 pounds, a weight reduction of 28%.

RECOMMENDATION

At this point in time, four different options can be pursued:

1. Testing on the partially composite CCN-150-5C can continue as is described in the previous section. The testing would probably reveal minor changes in the design and fabrication of the composite suction bell and pump bowl. Incorporating these changes, a final comprehensive manufacturing plan for fabricating these components would be delivered.
2. Focus could begin on fabricating several of the other CCN-150-5C's components out of composite materials. In particular, the motor housing first and, subsequently , the hydraulic motor itself. Referring to Table 1, these two parts are the remaining *heavy* components of the CCN-150-5C. Fabricating them out of composite materials would be a greater challenge than was found with either the pump bowl or suction bell. A possible fabrication plan for the motor housing would be to hybridize the design utilizing carbon composite for the housing shell in order to obtain a highly stiff and thin part; glass composite as an overwrap for protection; and stainless steel ends in order to make connections. The only possible plan for the hydraulic motor envisioned at this time would be to use metal matrix composites. The motor is a highly pressurized boundary in addition to

being a complex part geometrically. Metal matrix composites have the luxury of being able to be processed like metals, would have the mechanical resistance to high pressures necessary for this application, and would still result in a lighter-weight motor.

3. The third option to pursue at this time would be to design a composite transfer pump from the ground up. Many times the anisotropic nature of composites cannot be taken advantage of when parts are back-fitted into existing metallic designs. A new pump design would incorporate the advantages of the composite materials during the initial design stage making efficient use of their unique properties. In addition, the design would be a "standard" joint Navy-and-Coast Guard-owned design and eliminate the need to purchase foreign components.

4. Finally, focus could turn away from transfer pumps entirely and begin on other Coast Guard Strike Force equipment. The part that comes to mind is the diesel engine prime mover. The part is quite heavy and cumbersome. Significant auxiliary equipment is needed just to deliver it to the appropriate disaster site. A composite diesel engine, although extremely challenging and far sighted, would greatly enhance the response of the National Strike Teams.

Option three, the newly designed transfer pump, seems to be the most promising. A lightweight pump specifically designed with composites would probably result in the lightest pump possible. In addition, the design would be an American one, eliminating the need to purchase foreign equipment.

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APPENDIX A

SUMMARY OF STRAIN GAGE RESULTS

Suction Bell								
Gage Location	Flow Condition	Axial Strain (με)	45o Strain (με)	Circ. Strain (με)	Eps 1 (με)	Eps 2 (με)	Sig 1 (ksi)	Sig 2 (ksi)
	condition A (open)							
Left Side	condition B	Strain Gage Malfunctioned						
(0 Deg.)	condition C							
	condition D (closed)							
	condition A (open)	1.08	4.47	9.89	10.01	0.96	0.34	0.13
Front	condition B	3.66	11.17	23.60	23.90	3.36	0.82	0.35
(90 Deg.)	condition C	4.79	22.97	43.05	43.07	4.77	1.47	0.58
	condition D (closed)	11.49	36.05	62.82	62.84	11.47	2.19	1.00
	condition A (open)	1.22	2.87	24.86	28.63	-2.55	0.92	0.20
Right Side	condition B	9.54	8.29	32.19	37.79	3.94	1.26	0.50
(180 Deg.)	condition C	17.50	16.26	55.46	64.21	8.75	2.20	0.92
	condition D (closed)	29.98	26.36	73.31	83.44	19.65	2.95	1.48
	condition A (open)	3.51	5.74	12.89	13.50	2.90	0.47	0.23
Back	condition B	5.42	14.99	25.01	25.01	5.42	0.88	0.43
(270 Deg.)	condition C	10.52	27.11	41.87	41.90	10.49	1.48	0.76
	condition D (closed)	19.45	44.65	68.00	68.02	19.43	2.43	1.31

Pump Bowl								
		Axial Strain	45o Strain	Circ. Strain	Eps 1	Eps 2	Sig 1	Sig 2
Gage Location	Flow Condition	(με)	(με)	(με)	(με)	(με)	(ksi)	(ksi)
	condition A (open)							
Left Side	condition B	Strain Gage Malfunctioned						
(0 Deg.)	condition C							
	condition D (closed)							
	condition A (open)	0.65	3.90	4.55	4.94	0.26	0.17	0.06
Front	condition B	1.62	7.80	13.66	13.66	1.62	0.47	0.19
(90 Deg.)	condition C	1.30	12.35	24.07	24.07	1.30	0.81	0.28
	condition D (closed)	1.30	18.20	38.05	38.11	1.24	1.27	0.42
	condition A (open)	0.00	2.28	1.95	2.60	-0.65	0.08	0.00
Right Side	condition B	2.60	10.08	11.70	12.56	1.74	0.43	0.18
(180 Deg.)	condition C	6.17	17.55	20.15	21.41	4.91	0.75	0.37
	condition D (closed)	5.52	27.31	33.48	35.51	3.49	1.21	0.47
	condition A (open)	1.95	3.41	6.50	6.64	1.81	0.24	0.13
Back	condition B	5.85	11.30	18.51	18.57	5.79	0.67	0.37
(270 Deg.)	condition C	9.74	22.87	31.82	32.02	9.54	1.15	0.63
	condition D (closed)	10.05	29.36	51.31	51.35	10.01	1.79	0.84

Motor Housing								
		Axial Strain	45o Strain	Circ. Strain	Eps 1	Eps 2	Sig 1	Sig 2
Gage Location	Flow Condition	(με)	(με)	(με)	(με)	(με)	(ksi)	(ksi)
	condition A (open)	3.83	11.16	21.06	21.15	3.73	0.73	0.33
Left Side	condition B	9.57	25.83	47.86	48.07	9.35	1.68	0.78
(0 Deg.)	condition C	20.09	41.14	73.70	74.31	19.48	2.64	1.38
	condition D (closed)	36.35	66.97	111.99	112.67	35.67	4.07	2.29
	condition A (open)	7.02	7.65	18.62	20.83	5.01	0.74	0.37
Front	condition B	14.35	24.87	48.82	50.08	13.09	1.78	0.93
(90 Deg.)	condition C	21.37	43.05	77.85	78.60	20.62	2.80	1.46
	condition D (closed)	36.67	71.75	120.60	121.16	36.11	4.35	2.39
	condition A (open)	1.91	6.37	13.28	13.41	1.78	0.46	0.19
Right Side	condition B	6.06	20.72	35.86	35.86	6.06	1.24	0.55
(180 Deg.)	condition C	10.84	36.34	69.27	69.51	10.60	2.40	1.04
	condition D (closed)	19.44	62.15	104.87	104.87	19.44	3.65	1.68
	condition A (open)	6.70	14.34	22.28	22.28	6.70	0.80	0.44
Back	condition B	16.26	37.93	56.42	56.48	16.20	2.02	1.09
(270 Deg.)	condition C	25.83	58.96	89.56	89.59	25.80	3.21	1.74
	condition D (closed)	42.41	91.80	137.37	137.41	42.37	4.95	2.76

Vane 1								
		Radial Strain	45o Strain	Circ. Strain	Eps 1	Eps 2	Sig 1	Sig 2
Gage Location	Flow Condition	(με)	(με)	(με)	(με)	(με)	(ksi)	(ksi)
	condition A (open)	27.93	35.07	0.00	39.27	-11.34	1.18	0.01
Tip	condition B	38.97	50.01	1.95	55.33	-14.41	1.68	0.07
	condition C	49.68	62.02	14.61	66.79	-2.50	2.18	0.58
	condition D (closed)	58.13	66.57	38.97	68.96	28.14	2.55	1.61
	condition A (open)	15.61	-32.18	-46.79	19.75	-50.93	0.15	-1.48
Middle	condition B	19.51	-52.34	-58.80	31.37	-70.66	0.34	-2.02
	condition C	24.72	-58.92	-38.99	51.97	-66.24	1.06	-1.67
	condition D (closed)	31.55	-61.11	-52.87	55.12	-76.44	1.06	-1.97
	condition A (open)	5.85	7.47	7.79	7.99	5.65	0.32	0.27
Root	condition B	9.09	13.64	7.47	13.70	2.86	0.48	0.23
	condition C	12.99	10.72	7.14	13.06	7.07	0.50	0.36
	condition D (closed)	19.16	11.04	6.82	19.46	6.52	0.71	0.41

Vane 2								
Gage Location	Flow Condition	Radial Strain (με)	45o Strain (με)	Circ. Strain (με)	Eps 1 (με)	Eps 2 (με)	Sig 1 (ksi)	Sig 2 (ksi)
	condition A (open)	22.10	9.10	1.95	22.52	1.53	0.76	0.27
Tip	condition B	38.12	16.25	5.54	39.05	4.61	1.33	0.54
	condition C	48.29	27.96	12.57	48.46	12.40	1.72	0.89
	condition D (closed)	55.01	43.88	36.88	55.24	36.65	2.18	1.75
	condition A (open)	11.05	-11.70	-49.41	11.96	-50.32	-0.10	-1.54
Middle	condition B	15.60	-15.93	-51.04	15.65	-51.09	0.01	-1.53
	condition C	25.03	-23.08	-50.38	26.44	-51.79	0.36	-1.45
	condition D (closed)	34.13	-28.28	-52.99	38.03	-56.89	0.69	-1.50
	condition A (open)	6.83	-2.93	1.95	12.11	-3.33	0.37	0.01
Root	condition B	9.10	4.55	4.88	10.22	3.76	0.37	0.23
	condition C	13.33	5.53	7.48	16.09	4.72	0.58	0.31
	condition D (closed)	22.43	12.03	6.18	22.74	5.87	0.81	0.42

Discharge Tube		
		Axial Strain
Gage Location	Flow Condition	(με)
	hanging by hose only	13.2
Left Side	condition A (open)	14.15
(0 Deg.)	condition B	32.07
	condition C	49.99
	condition D (closed)	72.00
	hanging by hose only	14.15
Right Side	condition A (open)	12.89
(180 Deg.)	condition B	25.78
	condition C	48.10
	condition D (closed)	79.23
	hanging by hose only	-15.08
Back	condition A (open)	-5.66
(270 Deg.)	condition B	-10.68
	condition C	-10.68
	condition D (closed)	-25.14

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APPENDIX B

SUCTION BELL INNER PROFILE

z (inch)	radius (inches)	diameter (inches)	z (inch)	radius (inches)	diameter (inches)
0.000	5.436	10.872	5.000	4.103	8.206
0.250	5.436	10.872	5.250	3.983	7.966
0.500	5.436	10.872	5.500	3.878	7.756
0.750	5.436	10.872	5.750	3.789	7.578
1.000	5.436	10.872	6.000	3.716	7.432
1.250	5.436	10.872	6.250	3.657	7.314
1.500	5.428	10.856	6.500	3.611	7.222
1.750	5.409	10.818	6.750	3.578	7.156
2.000	5.376	10.752	7.000	3.558	7.116
2.250	5.330	10.660	7.250	3.552	7.104
2.500	5.271	10.542	7.500	3.546	7.092
2.750	5.198	10.396	7.750	3.539	7.078
3.000	5.109	10.218	8.000	3.602	7.204
3.250	5.003	10.006	8.250	3.709	7.418
3.500	4.884	9.768	8.500	3.829	7.658
3.750	4.756	9.512	8.750	3.989	7.978
4.000	4.625	9.250	9.000	4.186	8.372
4.250	4.493	8.986	9.250	4.418	8.836
4.500	4.362	8.724	9.500	4.696	9.392
4.750	4.231	8.462	9.750	5.125	10.250

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APPENDIX C

STATEMENT OF WORK FOR THE COMPOSITE SUCTION BELL

Statement of Work
CCN-150 Fiberglass Suction Bell, Stub No. 9463AN

Background: CDNSWC was tasked by the Coast Guard R&D Center to determine the feasibility of making all or part of the CCN-150 cargo transfer pump out of advanced composite materials in an effort to reduce its weight. The first phase of the study concluded that two main components of the pump, the suction bell and pump bowl, were the best candidates for composites. The Coast Guard has now tasked CDNSWC to begin the process of purchasing composite pump bowls and suction bells for the CCN-150 for further investigation and testing. This statement of work addresses the key concerns and requirements needed to fabricate a composite CCN-150 suction bell.

Description: The CCN-150 's overall dimensions are 28 inches in length and 12 inches in diameter A breakdown of the parts is included. The suction bell is clearly shown in this figure. The suction bell itself measures approximately 11 inches in length. Its diameter varies from approximately 12 inches at the inlet side, reaches a minimum at its midsection of about 7 inches, and increases to 12 inches at the outlet end. There are three radial ribs at the inlet end of the suction bell which are used to secure chopping blades. The chopping blades are attached to these ribs via bolting.

Design: Since the composite version of the suction bell must conform to the existing components of the CCN-150 pump, this effort becomes one of replication. The suction bell must be replicated out of composites so that it will function with the other components of the CCN-150. Details include:

- The bolt circles for attaching to the strainer at the inlet end and the pump bowl at the outlet end must be exact.
- The inside diameter profile along the suction bell's length must be replicated exactly. Measurements of this profile will be provided by CDNSWC.
- The outside diameter profile is not critical. The section thickness of the suction bell may be increased by increasing the outside diameter at any location as needed so long as the outside diameter does not exceed 12.25 inches at any location. However, the goal of the program is weight reduction so that increasing the outside diameter indiscriminately should be avoided.
- The suction bell should be fabricated out of glass reinforced polymeric material. The resin may be any structural vinyl ester or epoxy resin which can handle temperature excursions from about $0^{o}F$ to about $150^{o}F$ without loss of mechanical properties. The resin must be somewhat tough in that it should be able to withstand handling impacts. The reinforcement should consist of primarily continuous fibers with some chopped fibers allowed in order to provide outer protection/resin rich regions.

A detailed drawing along with the existing suction bell will be provided to the contractor while the parts are being fabricated. Any technical questions should be directed to:

Harry K. Telegadas
Code 644, CDNSWC
410-293-2165 (voice)
410-293-2530 (fax)

Delivery: Delivery of two composite suction bells is due 90 days after receipt of contract.

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APPENDIX D

RATIONAL FOR THE PURCHASE OF A COMPOSITE PUMP BOWL FROM THE SIMS PUMP VALVE COMPANY

28 April 1994

References:

(a) Military Interdepartmental Purchase Request (MIPR) Number Z51100-3-E00608 (NSF Transfer Pump Upgrade) dated 23 June 1993.

(b) Telegadas, H. K., "Feasibility of Using Composite Materials to reduce the Weight of the CCN-150-5C Transfer Pump", CARDEROCKDIV-SSM-64-94/07 (March 1994).

(c) Suitt, D. W., "Composite Pumps for Shipboard Use - Final Summary Report", DTRC-PAS-88-25 (august 1988).

The USCG R&D Center in Groton,. CT has funded via Reference (a) the Annapolis Detachment of NSWCCD to determine the feasibility of using composite materials to reduce the weight of CCN-150 Submersible Pumps. These pumps are used by the Coast Guard's National Strike Force and the Navy's Supervisor of Salvage for emergency off loading of petroleum products from stranded commercial tanker ships and Navy oilers. NSWCCD engineers from Codes 644 and 823 have combined forces to execute this project. The first phase of the project, which has recently been completed, required NSWCCD engineers to assess the feasibility of fabricating each of the major components of the CCN-150 pump subsystem from an appropriate composite material and to specify fiber-reinforced polymer-matrix laminates, processing techniques, weight-reduction expectations, technological risks, and rough cost estimates associated with the recommended alternative lightweight materials. The USCG R&D Center then reviewed the preliminary NSWCCD recommendations and provided direction regarding the second phase of the project during which selected pump components would be prototyped and evaluated.

Detailed results of the NSWCCD Phase 1 feasibility study for this project have been documented in Reference (b) which our Coast Guard sponsor has recently reviewed and approved fro final publication. NSWCCD has been requested to proceed with the construction and laboratory evaluation of three major components of the CCN-150 pump: the suction bell, the pump bowl, and the motor housing. In the case of the suction bell and the motor housing, it is expected that competitive procurement actions will be in the Government's best interest. However, in the case of the pump bowl described in the attached purchase request, several special

considerations apply which have led us to recommend a sole-source procurement from Sims Pump Valve Company.

The pump bowl consists of three interconnecting parts: a center hub, five vanes, and an outer ring. The outer ring must be precisely drilled with many through holes that allow it to be sandwiched between the suction bell and motor housing during pump assembly. A readily machinable composite material resistant to delamination is desired for the outer ring construction. NSWCCD's experience with a wide variety of commercial composite materials over the last decade has demonstrated that proprietary composite formulations from Sims Pump Valve Company are among the easiest, fastest, safest, and most predictable for extensive machining operations.

The five vanes in the pump bowl of the CCN-150 act to recover energy from the internal swirling flow as it leaves the rotating impeller. The metallic impeller (currently fabricated in stainless steel that may be replaced by a titanium alloy in the near future) is immediately upstream of the pump bowl and is designed to operate over a wide range of flow conditions. Consequently, the composite material selected for the vanes in the pump bowl must offer excellent resistance to severe erosion, recirculation and potential cavitation conditions that are likely to be experienced directly downstream of the impeller.

A comparison of the erosion and the cavitation resistance of six different composite materials from five U. S. commercial pump manufacturers was conducted by NSWCCD researchers in the mid 1980's and documented in Reference (c) to establish a technical data base for the use of composite materials in Navy and marine centrifugal pumps. results of the cavitation and erosion studies detailed in reference (c) show that a proprietary composite material called "Simsite" manufactured by the Sims Pump Valve Company gave superior performance over all the other composites evaluated when both cavitation and erosion results were combined (see Figs. 33 and 34 of Reference (c)).

Therefore, in order to minimize the risk of high-velocity erosion and cavitation damage to the pump bowl vanes and to provide a highly machinable composite material to satisfy the complexities of vane manufacture, it is in the Government's best interest to sole-source fabrication of the prototype composite pump bowl from the Sims Pump Valve Company

APPENDIX E

SUMMARY OF TEST RESULTS

Test Run A				
Pump:	USCG PM-049 (stainless steel CCN-150-5C)			
Prime Mover:	USCG PM-073			
	Discharge	Suction	Differential	
Flow	Pressure	Pressure	Pressure	Flow Rate
Condition	(psig)	(psig)	(psi)	(gpm)
A-1 (open)	17.5	0	15.0	1440
A-2	20.0	0	17.5	1360
A-3	26.0	0	24.0	1180
A-4	30.0	0	27.0	1020
A-5	37.5	0	35.5	750
A-6	46.0	0	44.0	530
A-7	53.5	0	51.5	310
A-8	57.0	0	56.5	160
A-9	60.0	0	58.5	50
A-10 (closed)	62.0	0	60.0	0
Test Run B (Repeat of Run A)				
Pump:	USCG PM-049 (stainless steel CCN-150-5C)			
Prime Mover:	USCG PM-073			
	Discharge	Suction	Differential	
Flow	Pressure	Pressure	Pressure	Flow Rate
Condition	(psig)	(psig)	(psi)	(gpm)
B-1 (open)	18.0	0	16.5	1510
B-2	25.0	0	23.0	1310
B-3	30.0	0	28.0	1120
B-5	35.0	0	33.0	900
B-5	57.5	0	56.0	170
B-6 (closed)	61.5	0	60.0	0

Test Run C				
Pump:	No Serial No. (stainless steel CCN-150-5C)			
Prime Mover:	USCG PM-070			
	Discharge	Suction	Differential	
Flow	Pressure	Pressure	Pressure	Flow Rate
Condition	(psig)	(psig)	(psi)	(gpm)
C-1 (open)	18.5	0	16.5	1510
C-2	22.0	0	19.0	1420
C-3	26.0	0	24.0	1250
C-4	29.5	0	27.5	1070
C-5	35.5	0	33.5	860
C-6	44.0	0	42.0	620
C-7	53.0	0	51.0	360
C-8	57.0	0	55.5	170
C-9	59.0	0	57.0	90
C-10 (closed)	61.0	0	59.5	0
Test Run D				
Pump:	No Serial No. (compositized CCN-150-5C)			
Prime Mover:	USCG PM-070			
	Discharge	Suction	Differential	
Flow	Pressure	Pressure	Pressure	Flow Rate
Condition	(psig)	(psig)	(psi)	(gpm)
D-1 (open)	17.5	0	15.0	1420
D-2	21.0	0	18.0	1320
D-3	26.5	0	24.0	1150
D-4	31.5	0	29.0	970
D-5	39.0	0	37.0	730
D-6	45.5	0	43.5	530
D-7	50.5	0	49.0	310
D-8	52.5	0	51.0	190
D-9	53.5	0	51.5	75
D-10 (closed)	55.0	0	53.0	0

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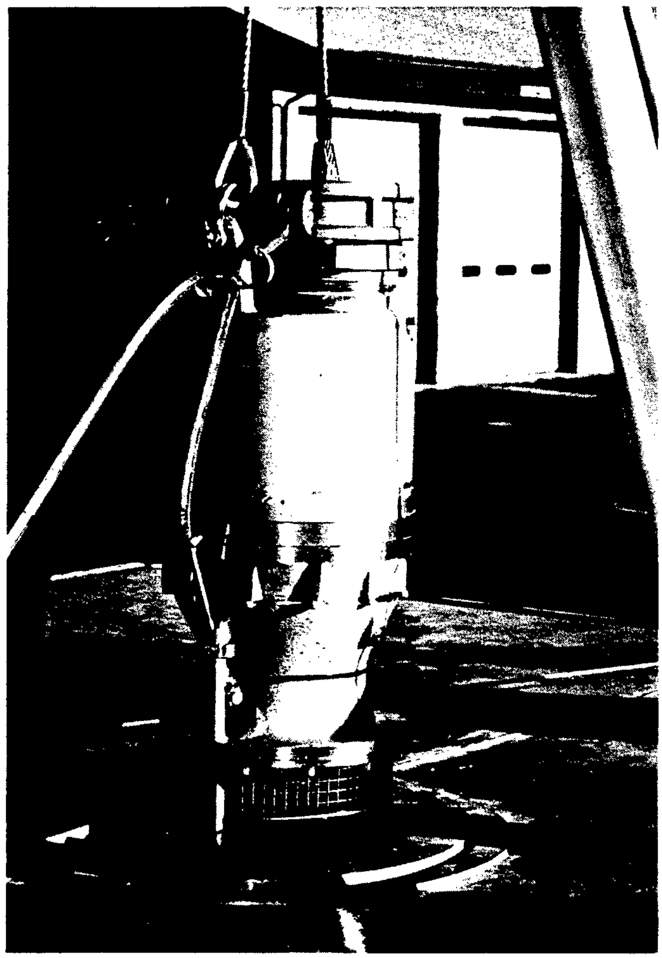

Fig. 1. Photograph of the CCN-150-5C.

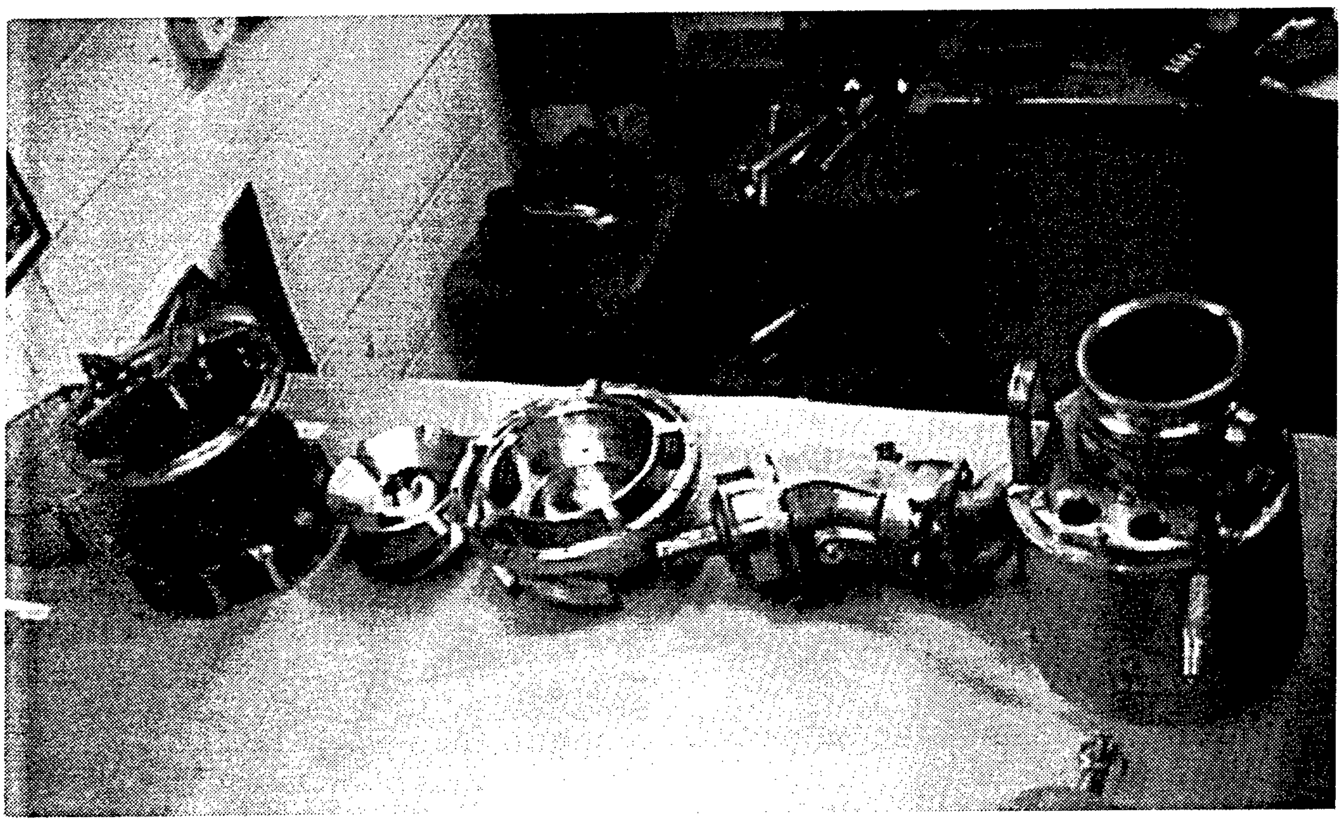

Fig. 2. Photograph of the disassembled CCN-150-5C.

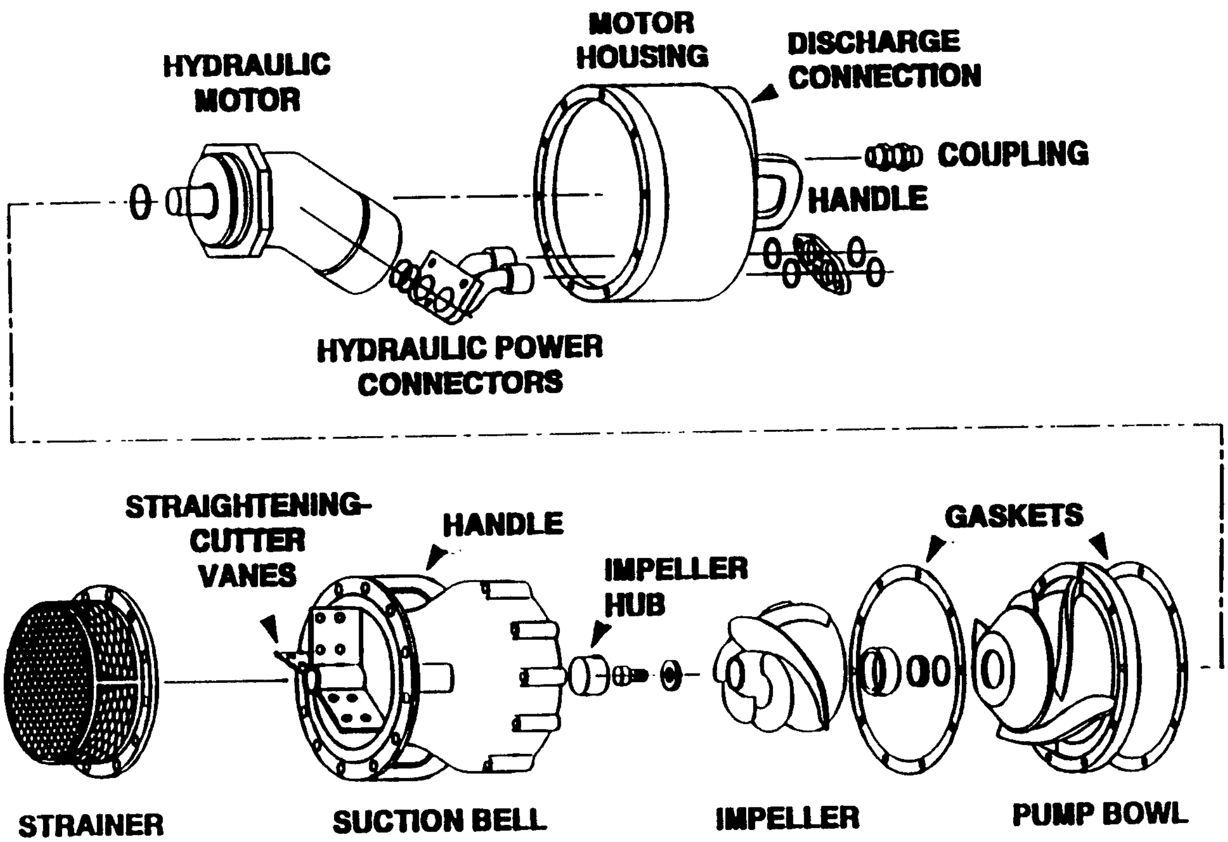

Fig. 3. Schematic of the disassembled CCN-150-5C.

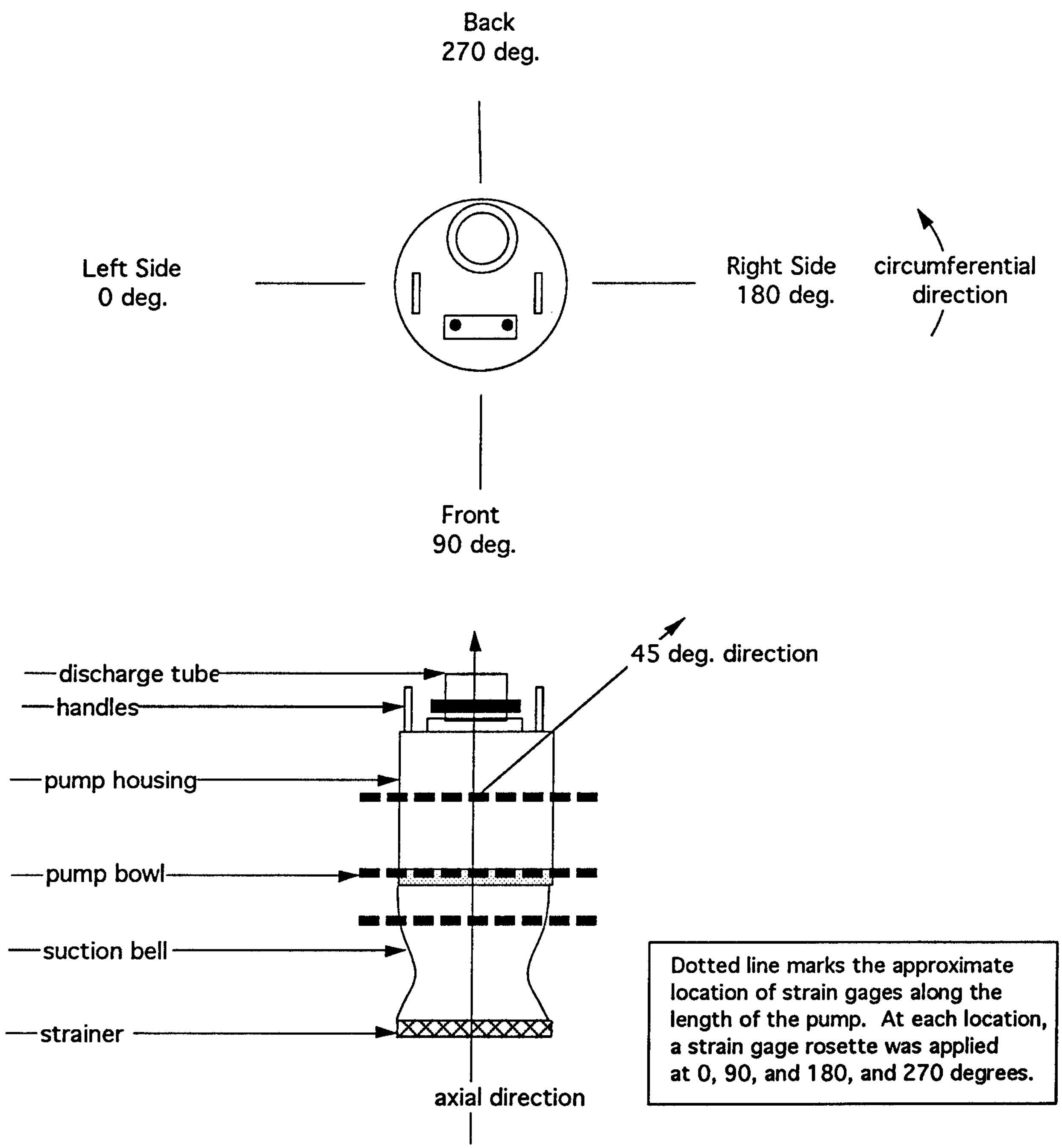

Fig. 4. Schematic of the CCN-150-5C showing location of strain gages.

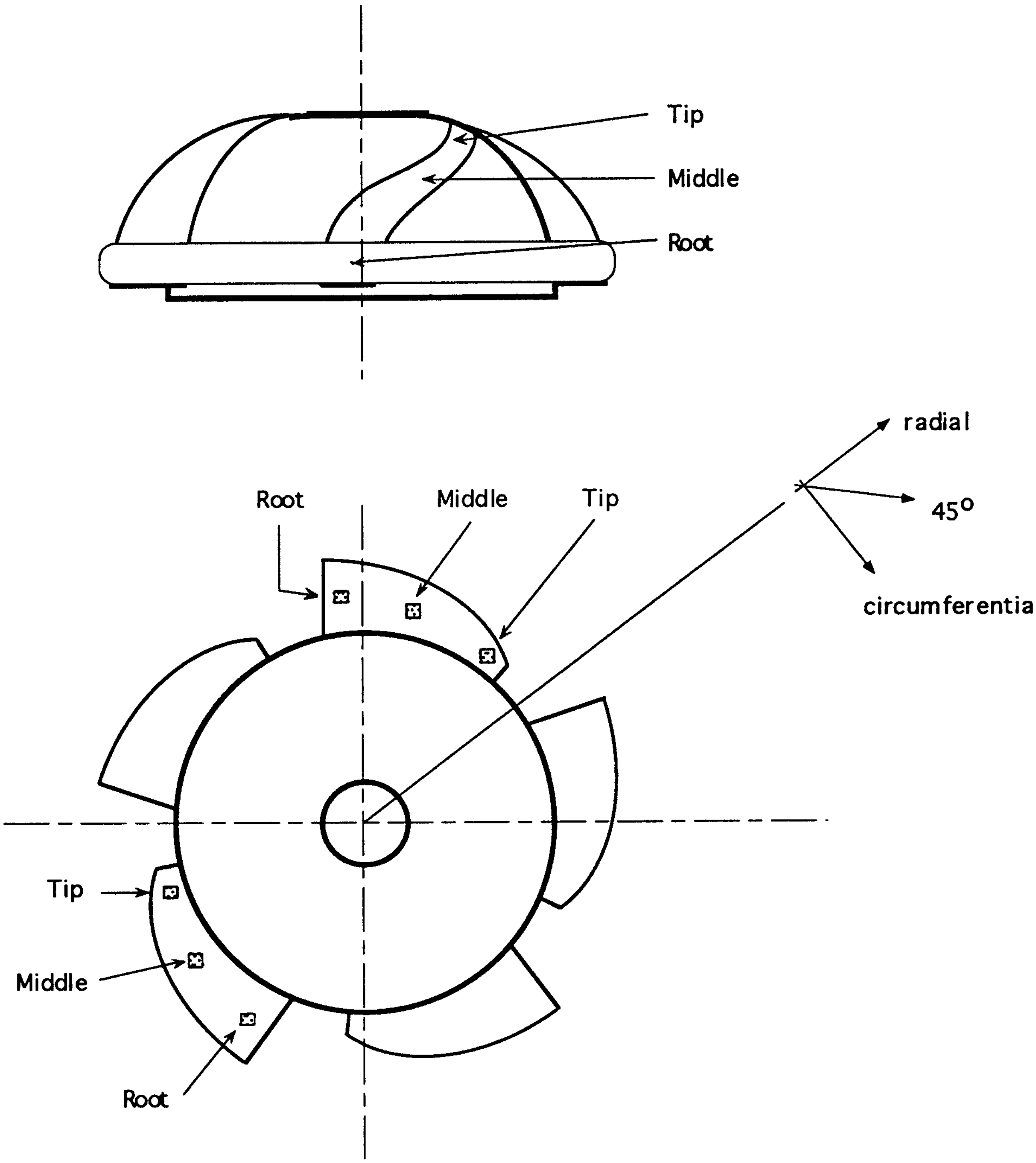

Fig. 5. Schematic of the CCN-150-5C's pump bowl showing location of strain gages.

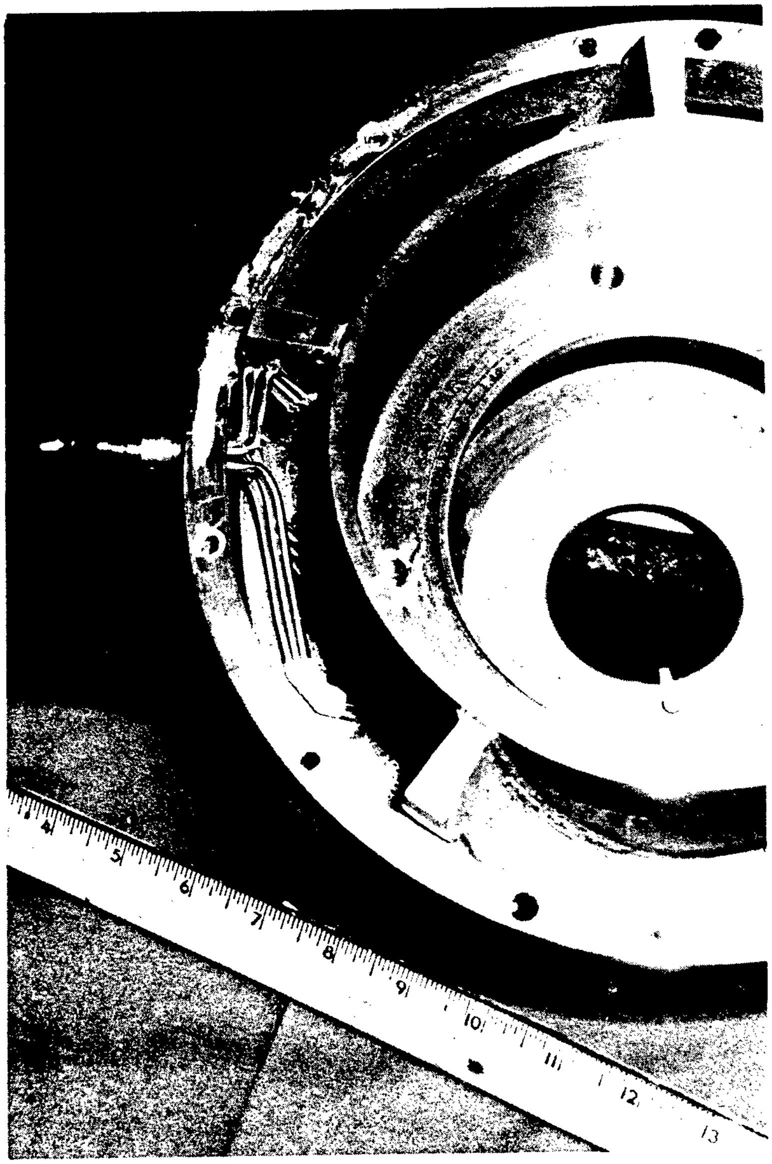

Fig. 6. Photograph of the instrumented pump bowl.

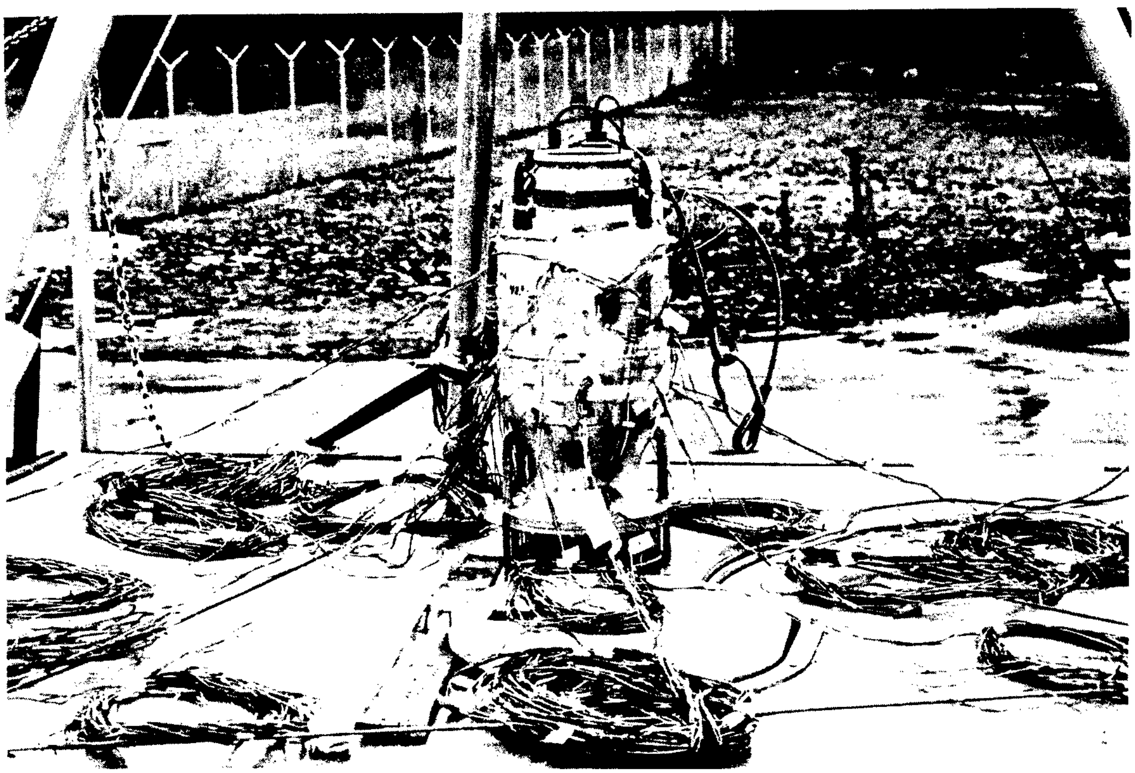

Fig. 7. Instrumented CCN-150-5C.

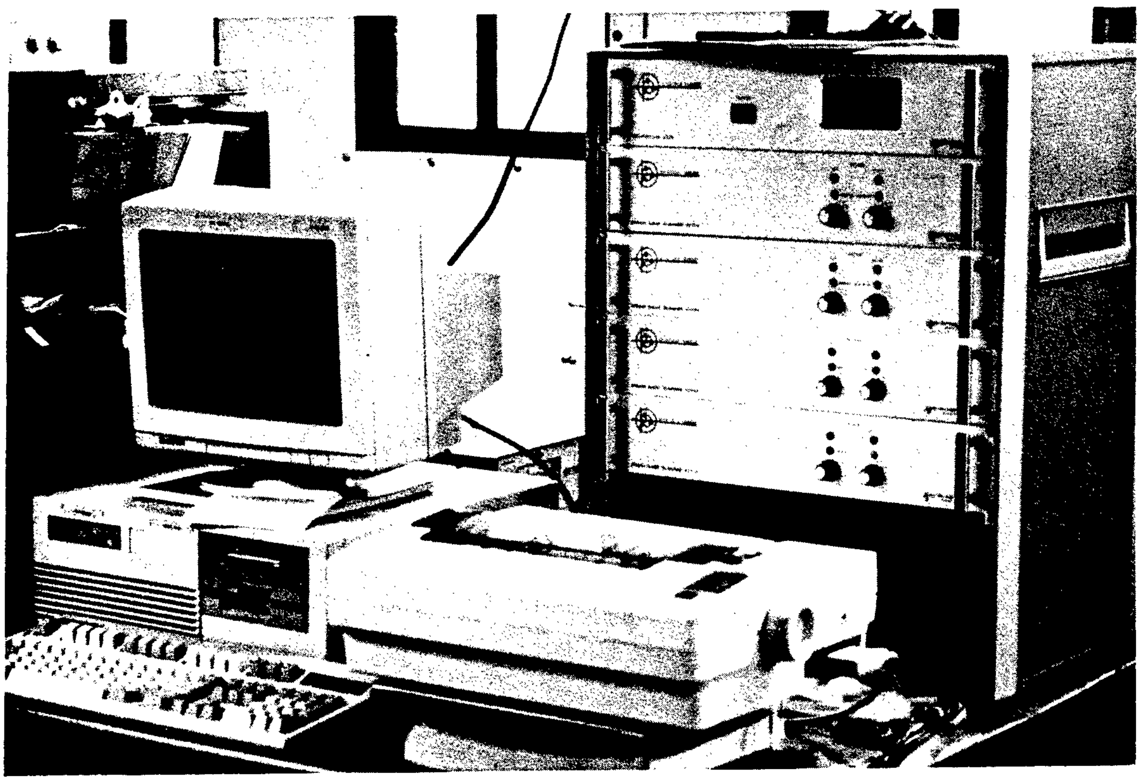

Fig. 8. Photograph of the data acquisition system.

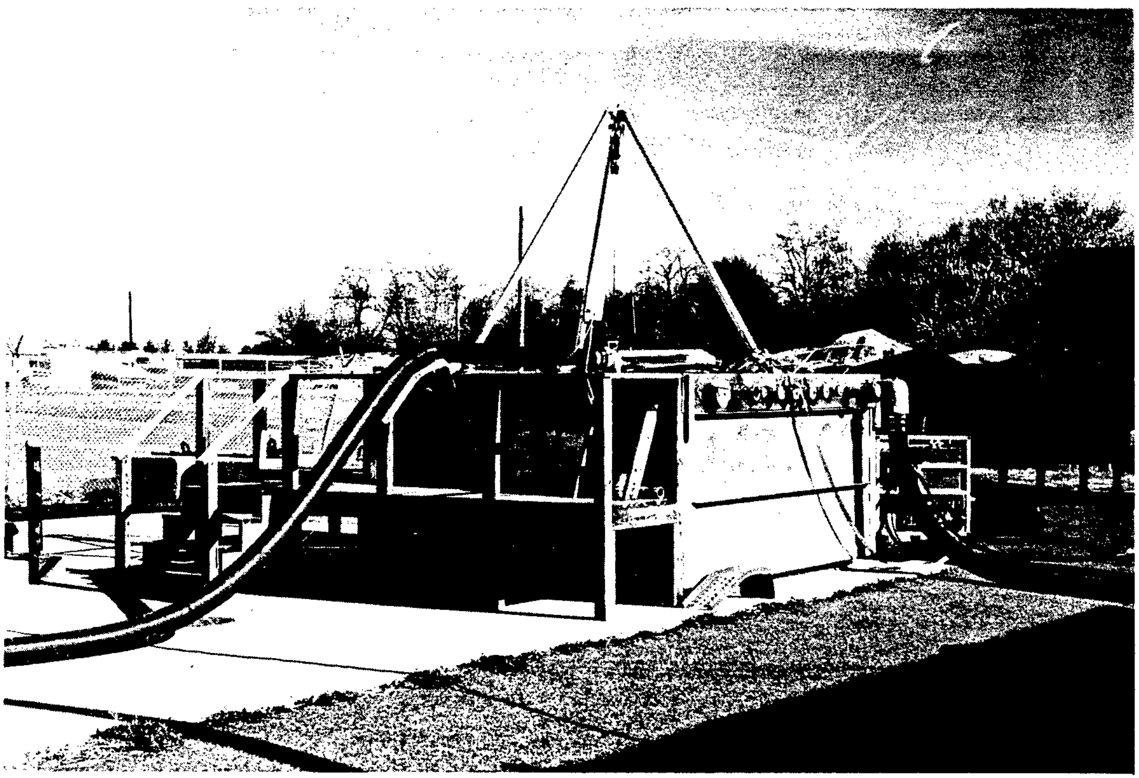

Fig. 9. Photograph of the test tank.

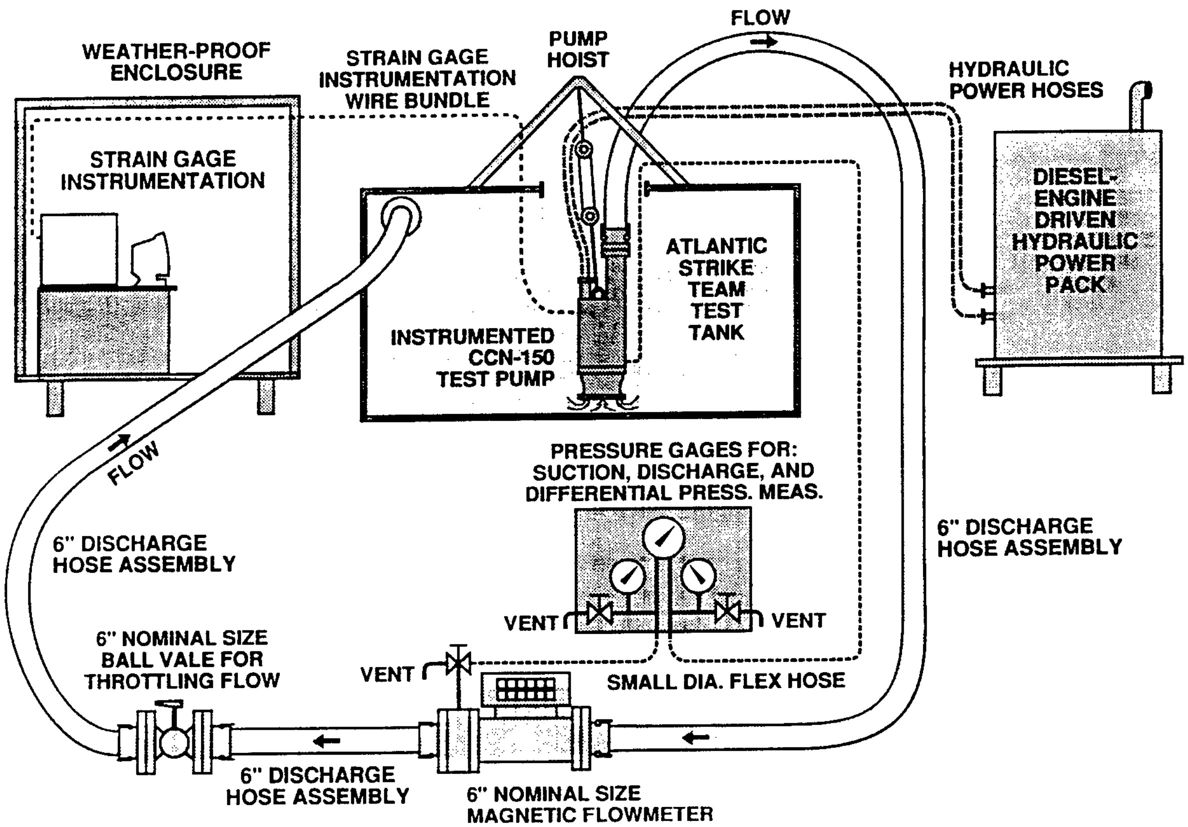

Fig. 10. Schematic of the test loop.

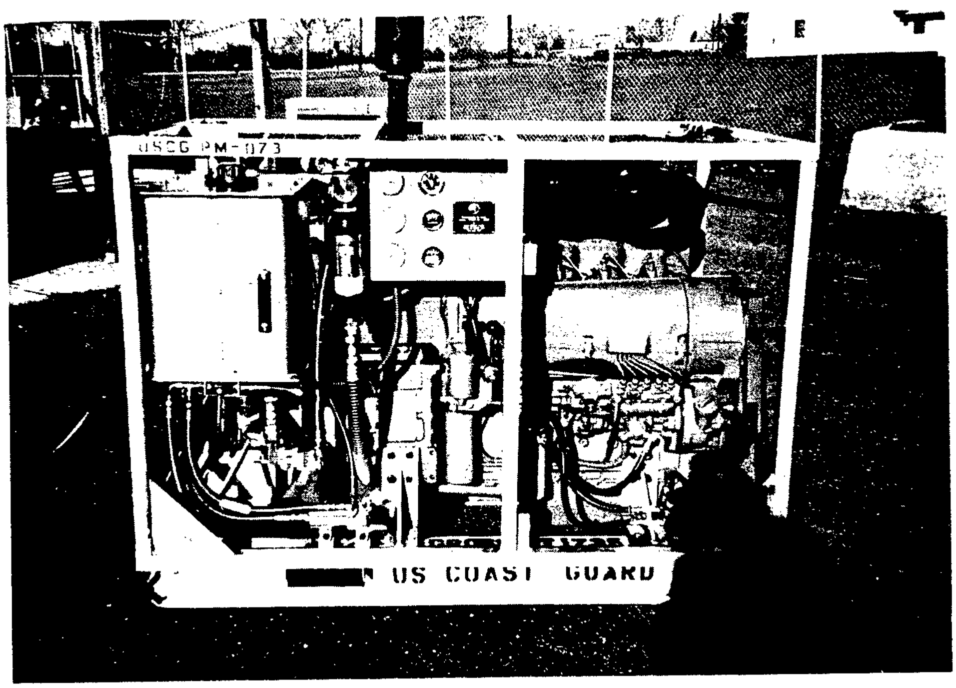

Fig. 11. Photograph of the prime mover.

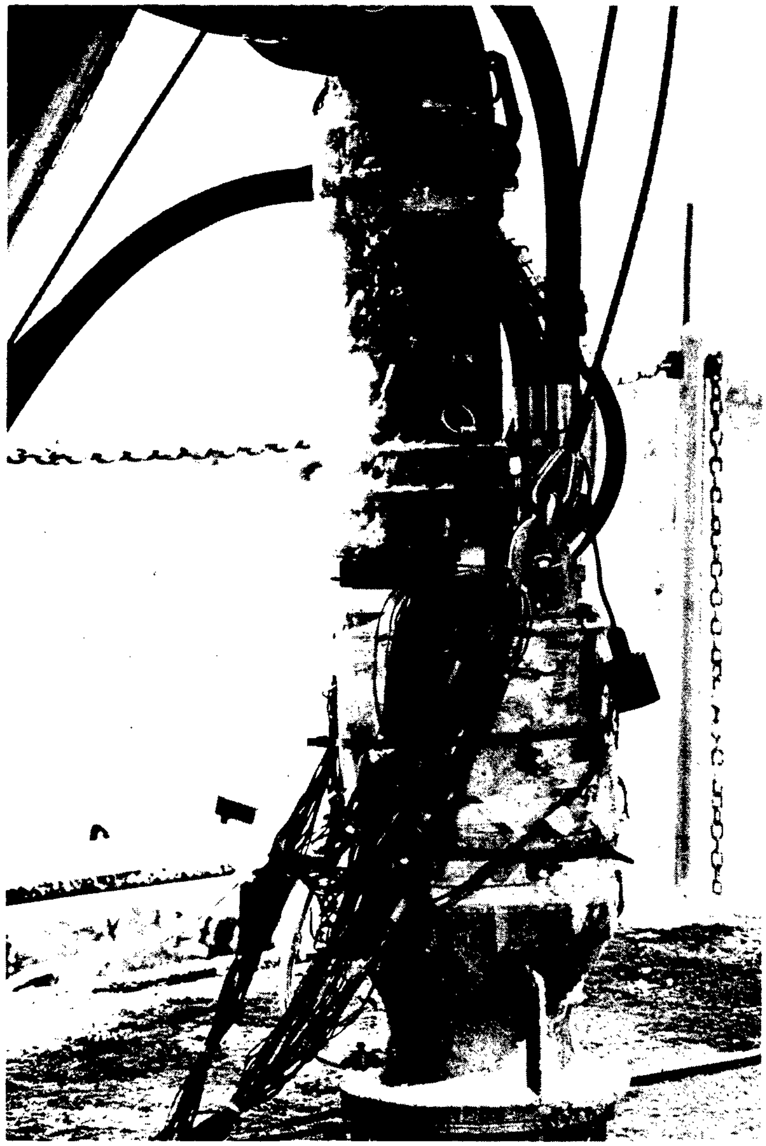

Fig. 12. Photograph of the CCN-150-5C with the hydraulic and discharge lines attached.

Fig. 13. Photograph of the magnetic flow meter.

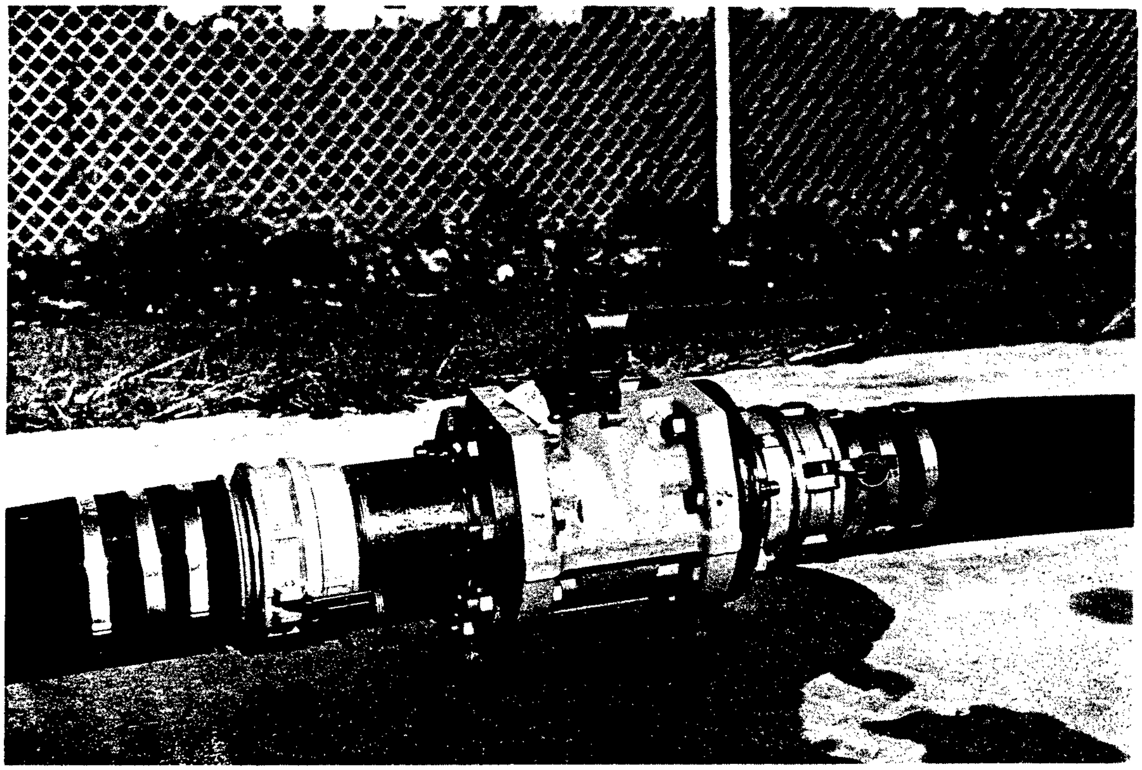

Fig. 14. Photograph of the ball valve used to regulate flow.

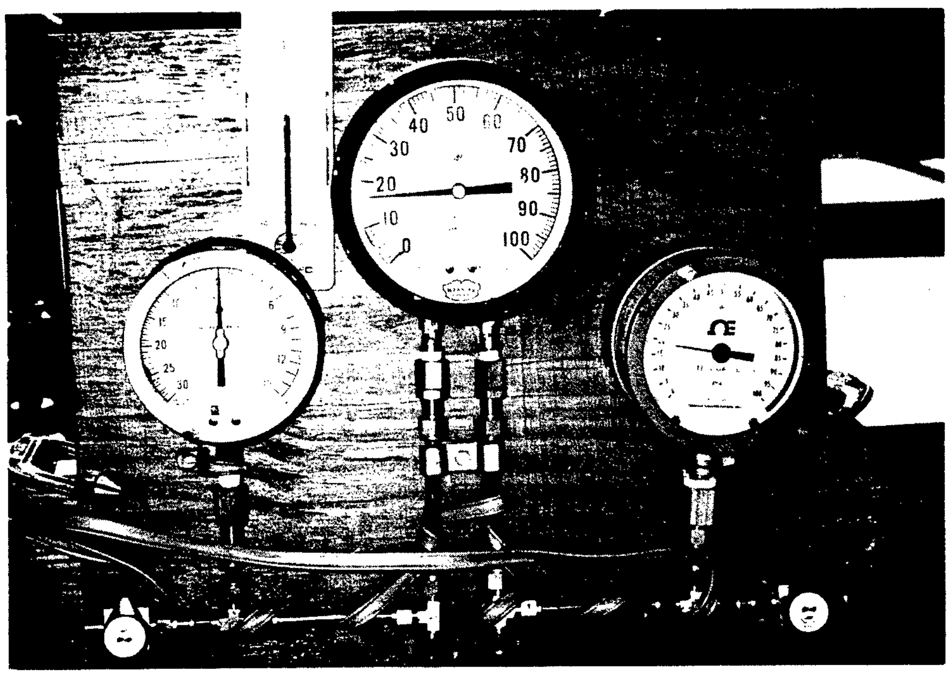

Fig. 15. Photograph of the pressure measuring equipment.

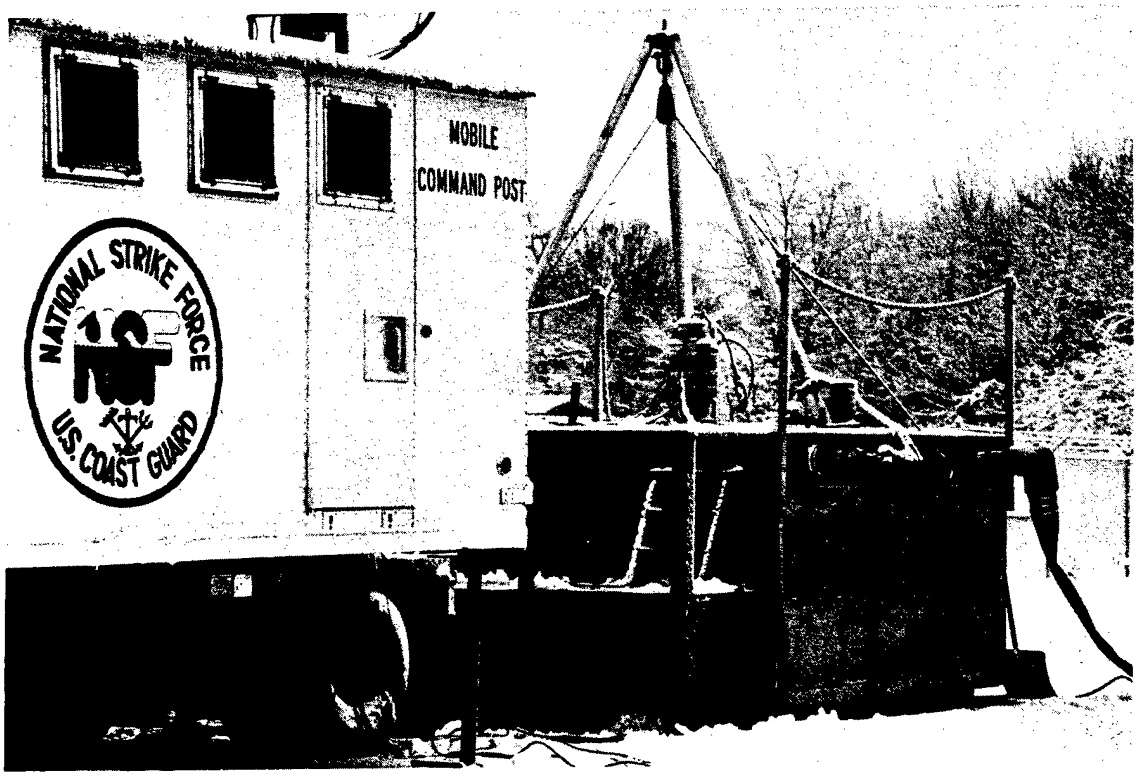

Fig. 16. Photograph of the NSF Mobil Command Unit.

Fig. 17. Photograph of the CCN-150-5C submerged and operating in the test tank.

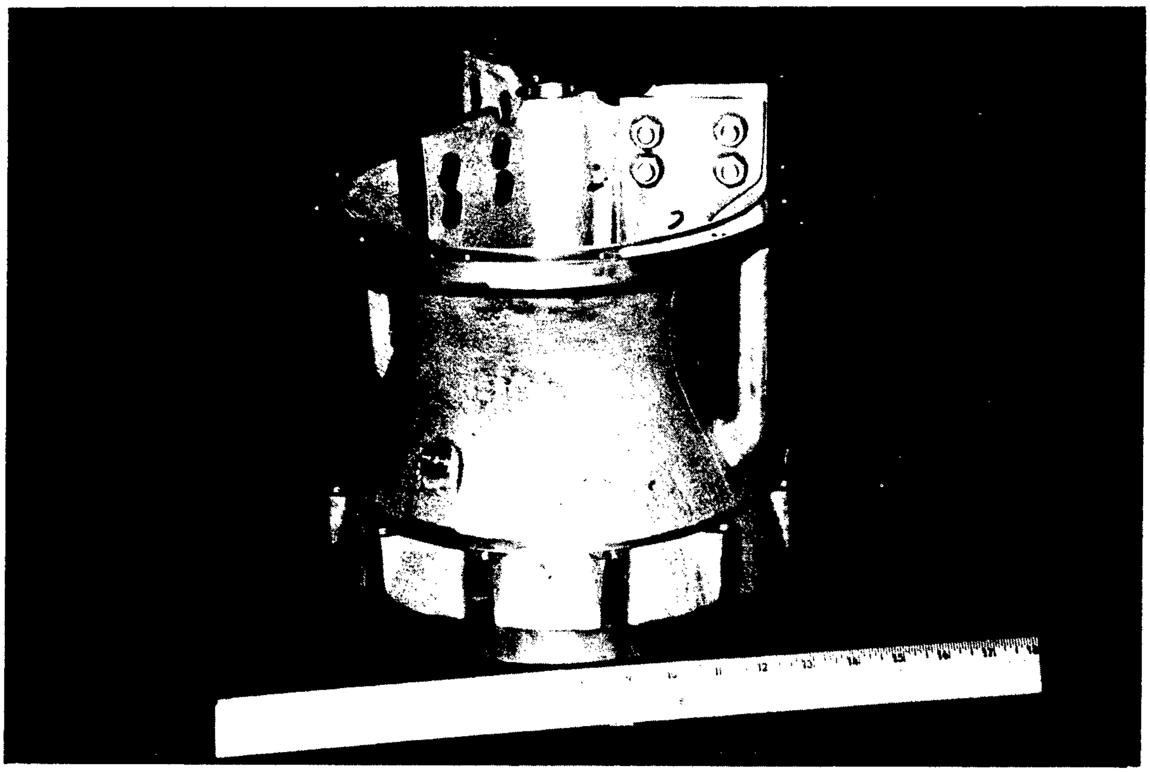

Fig. 18. Photograph of the suction bell.

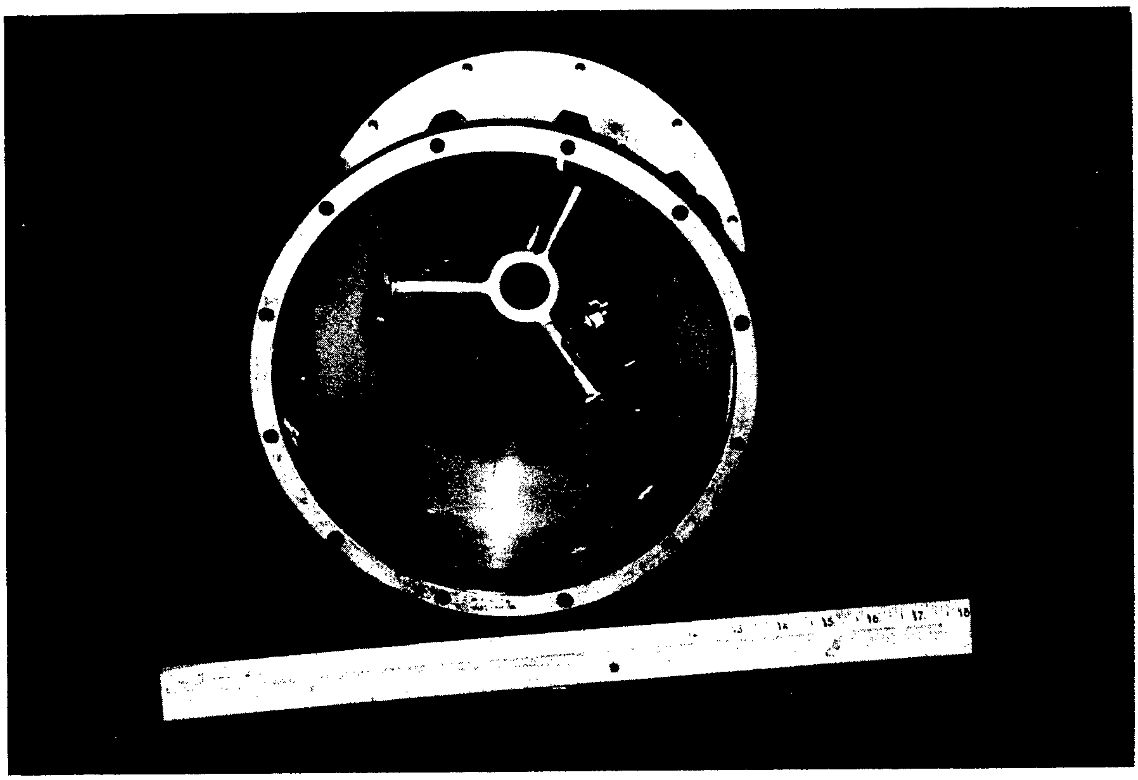

Fig. 19. Photograph of the suction bell, alternate view.

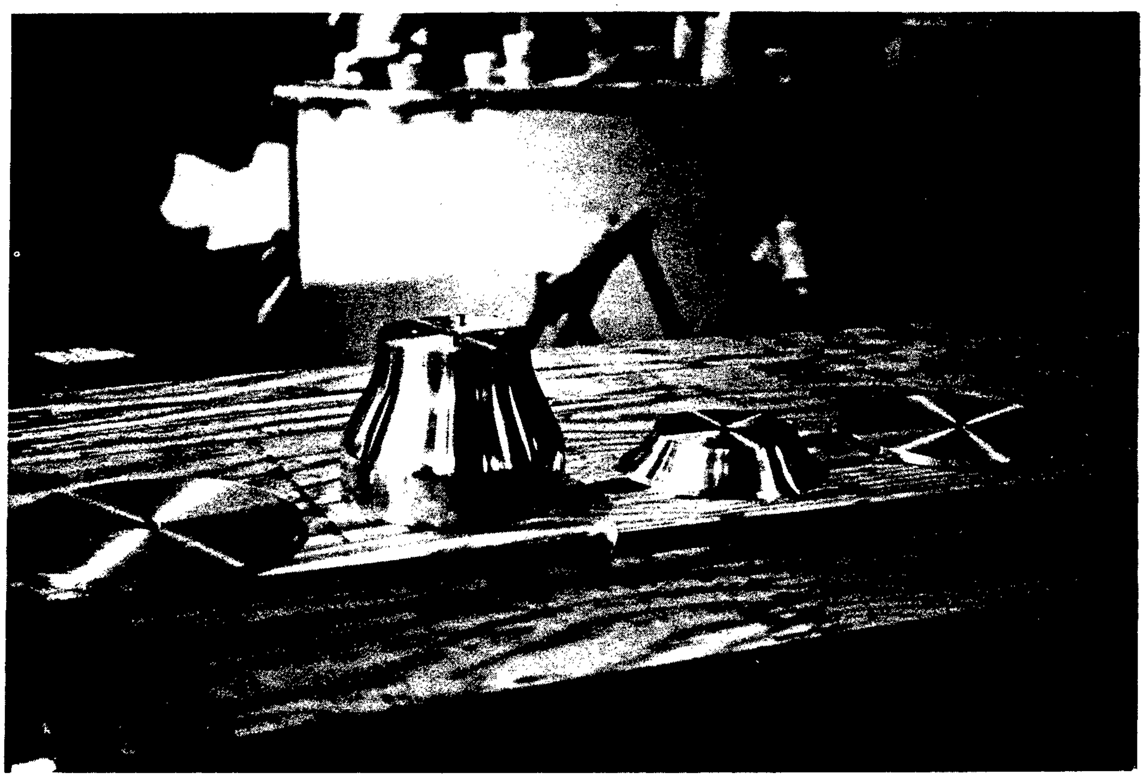

Fig. 20. Photograph of the disassembled mold used to fabricate a composite suction bell.

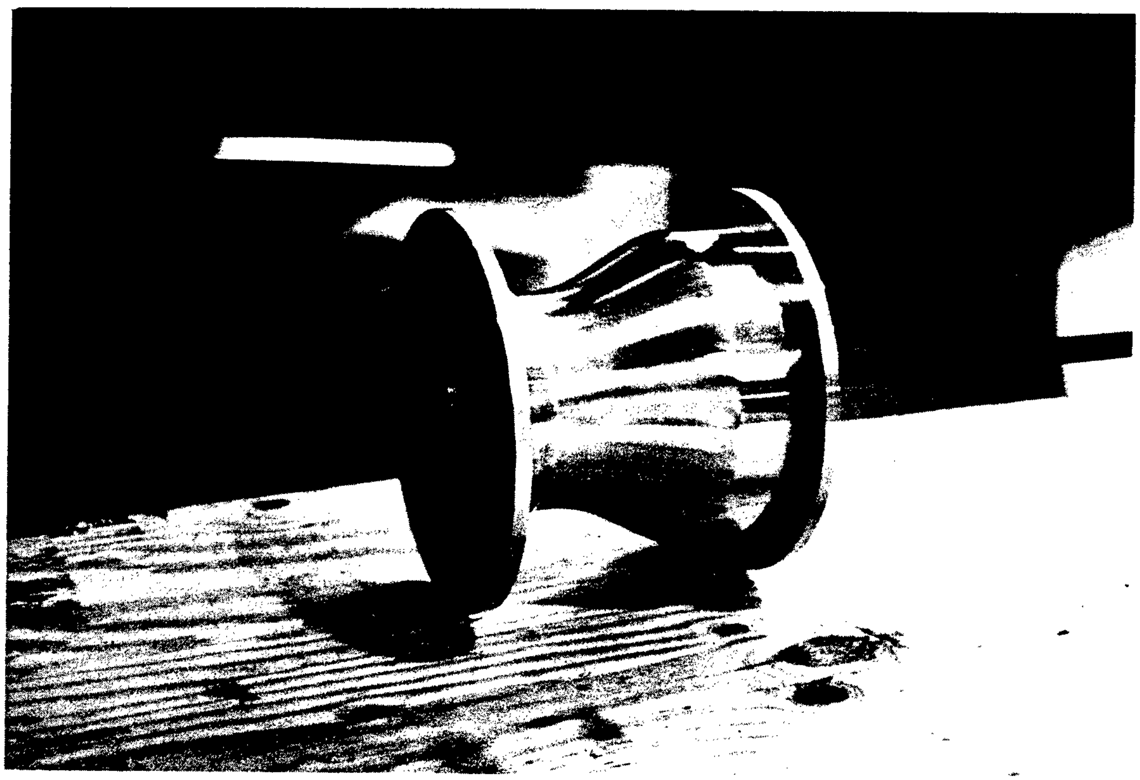

Fig. 21. Photograph of the assembled mold used to fabricate a composite suction bell.

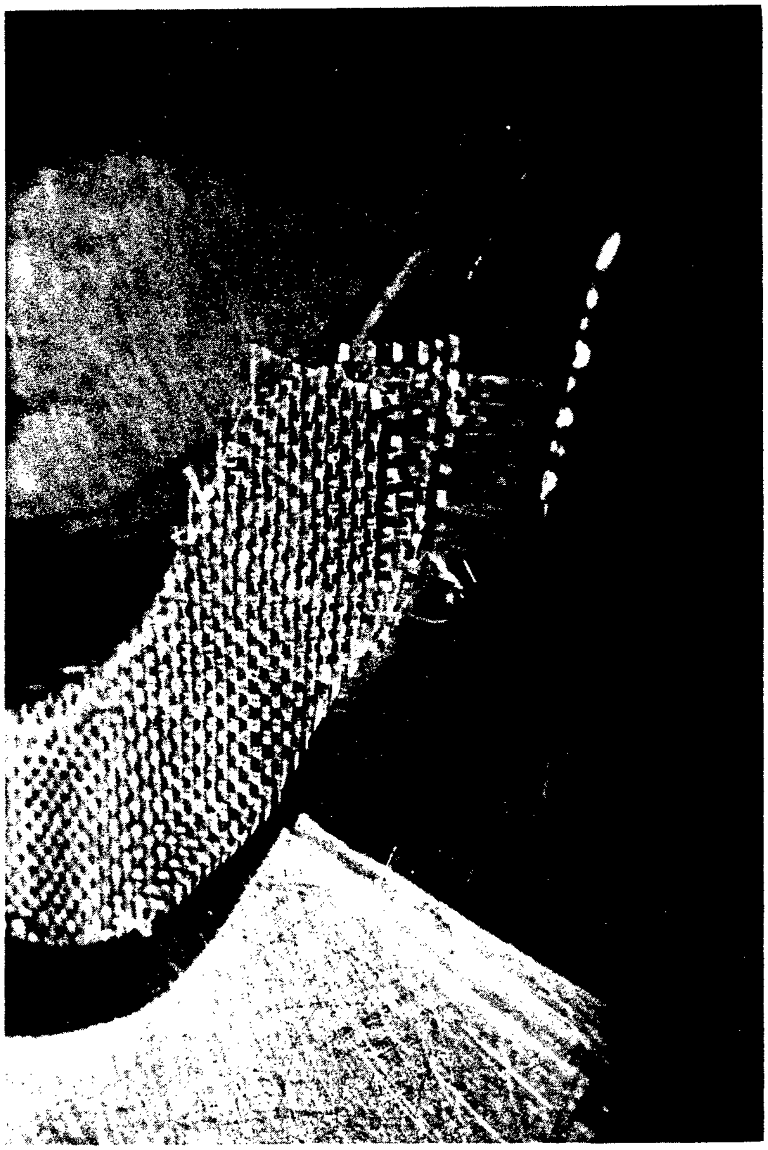

Fig. 22. Constituent materials used to fabricate a composite suction bell.

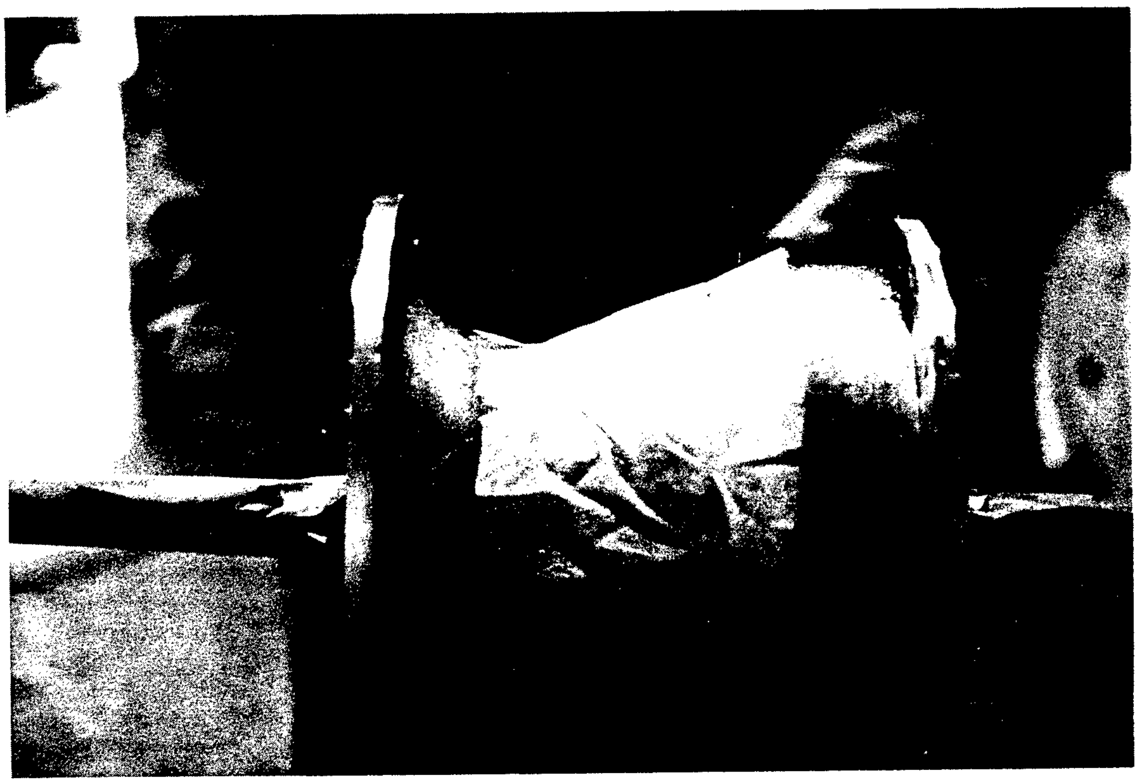

Fig. 23. Fabricating the composite suction bell, applying the c-veil layer.

Fig. 24. Fabricating the composite suction bell, applying a chopped mat layer.

Fig. 25. Fabricating the composite suction bell, applying a woven roving layer.

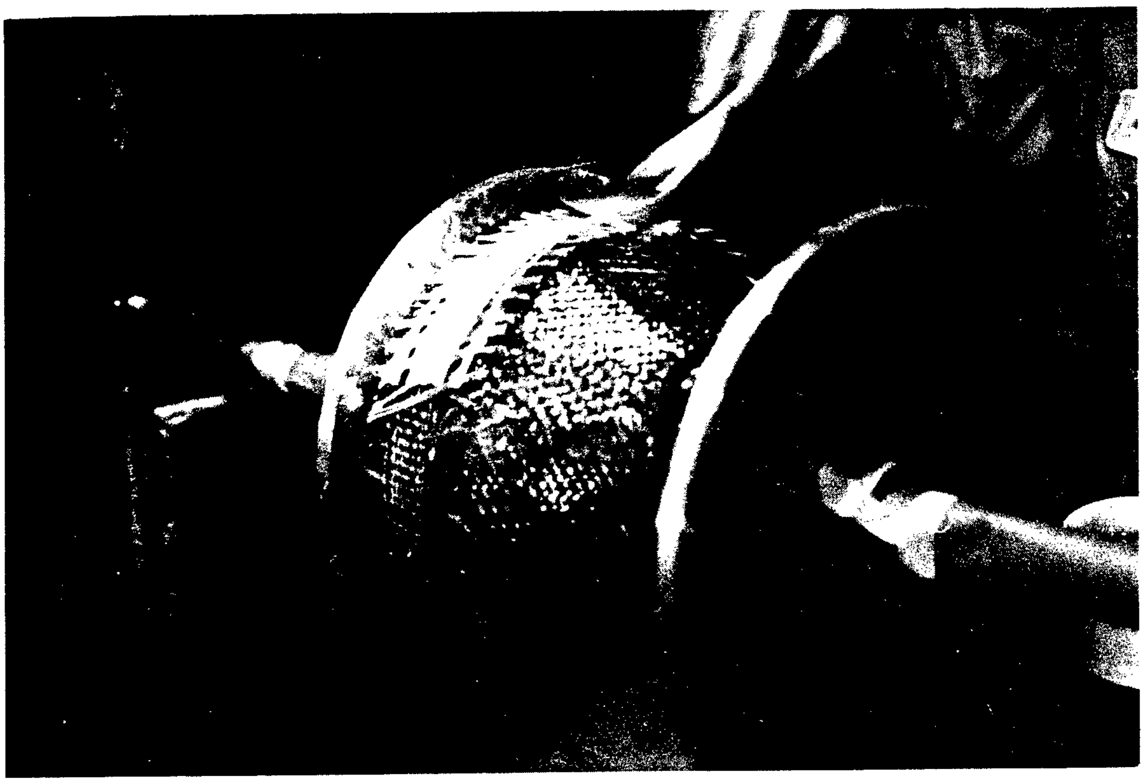

Fig. 26. Fabricating the composite suction bell, applying resin.

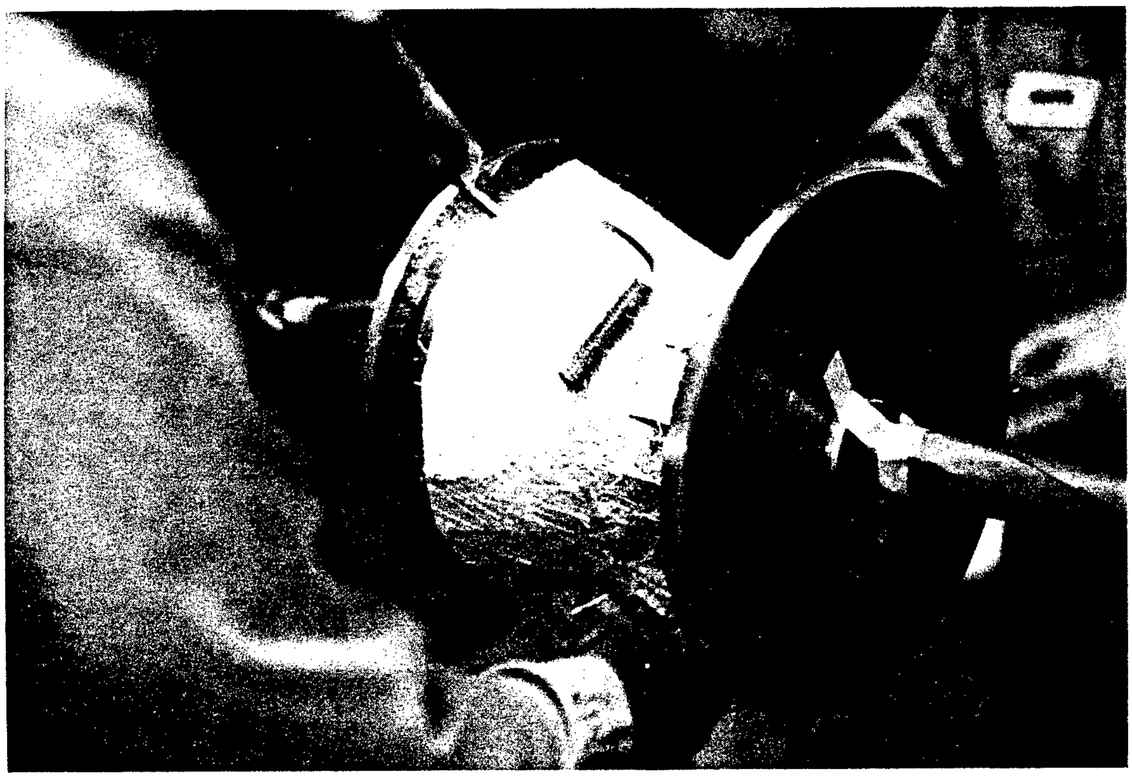

Fig. 27. Fabricating the composite suction bell, compacting layers.

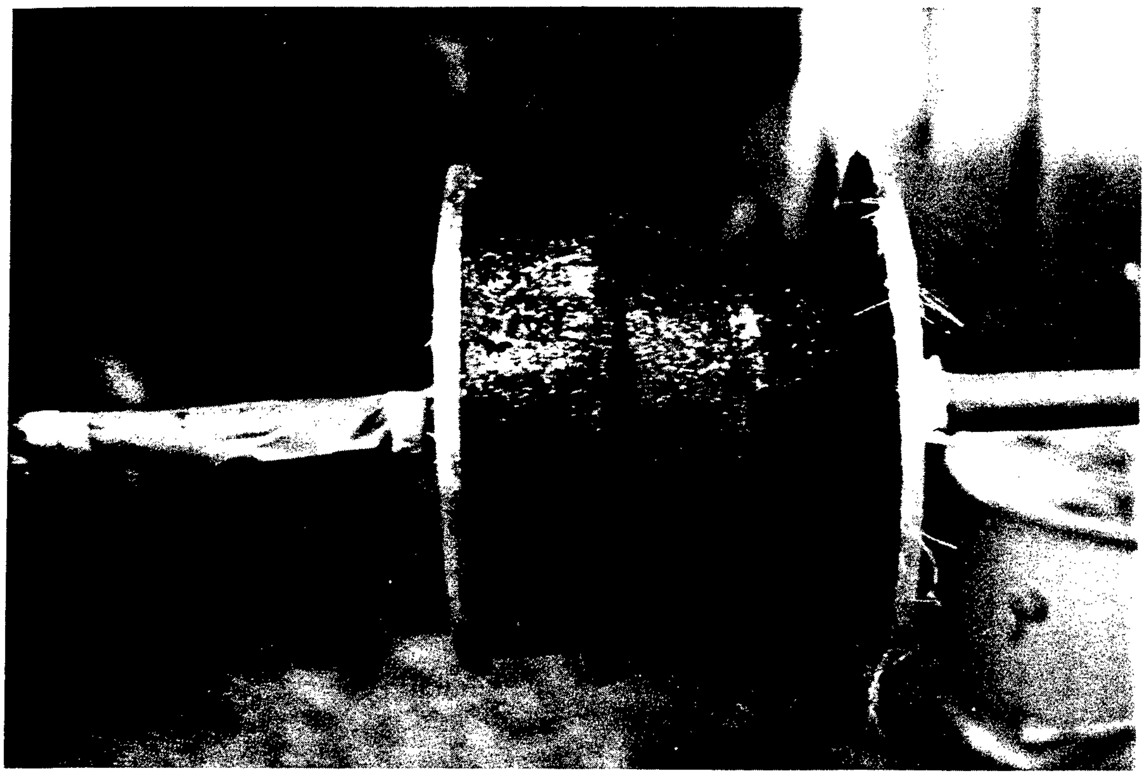

Fig. 28. Fabricating the composite suction bell, curing.

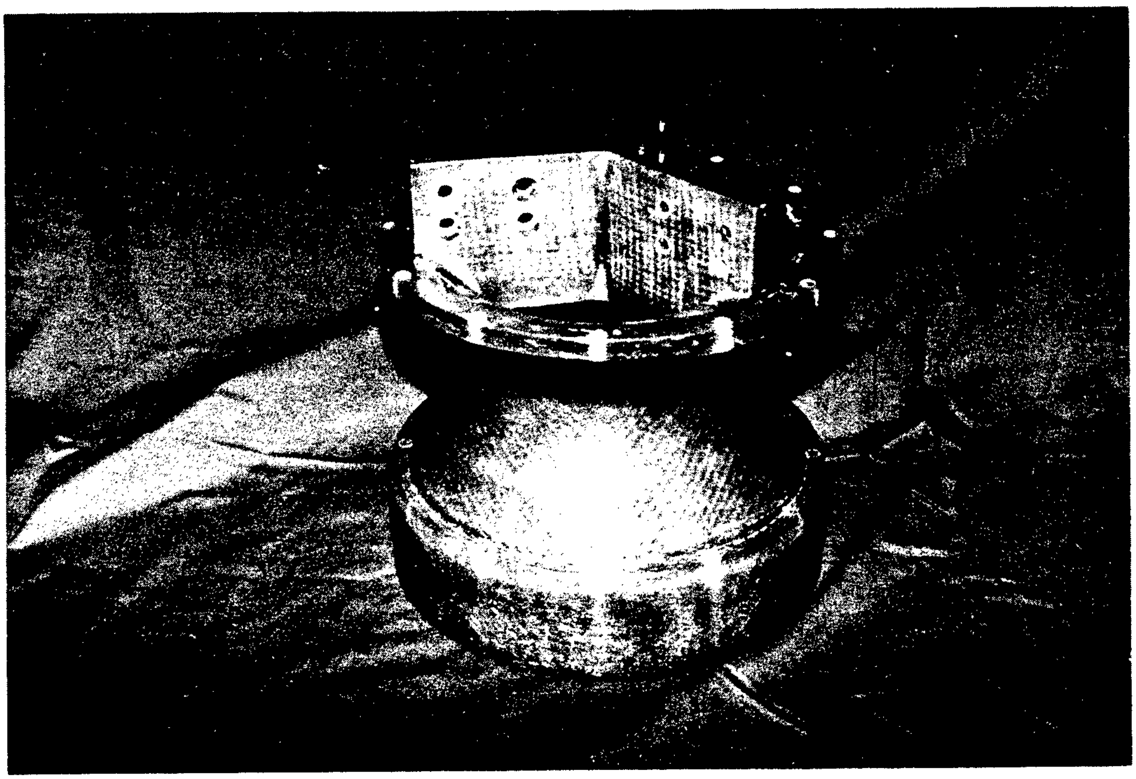

Fig. 29. Photograph of the finished composite suction bell.

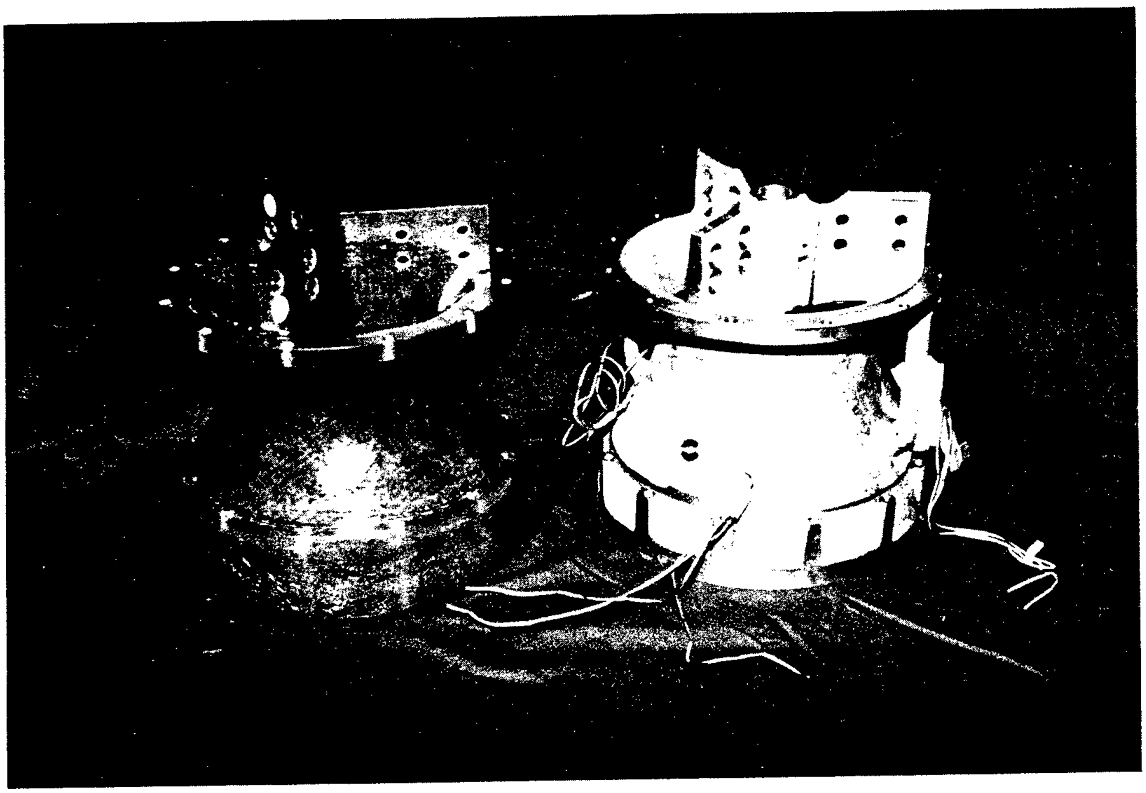

Fig. 30. Photograph of the finished composite suction bell next to its metallic counterpart.

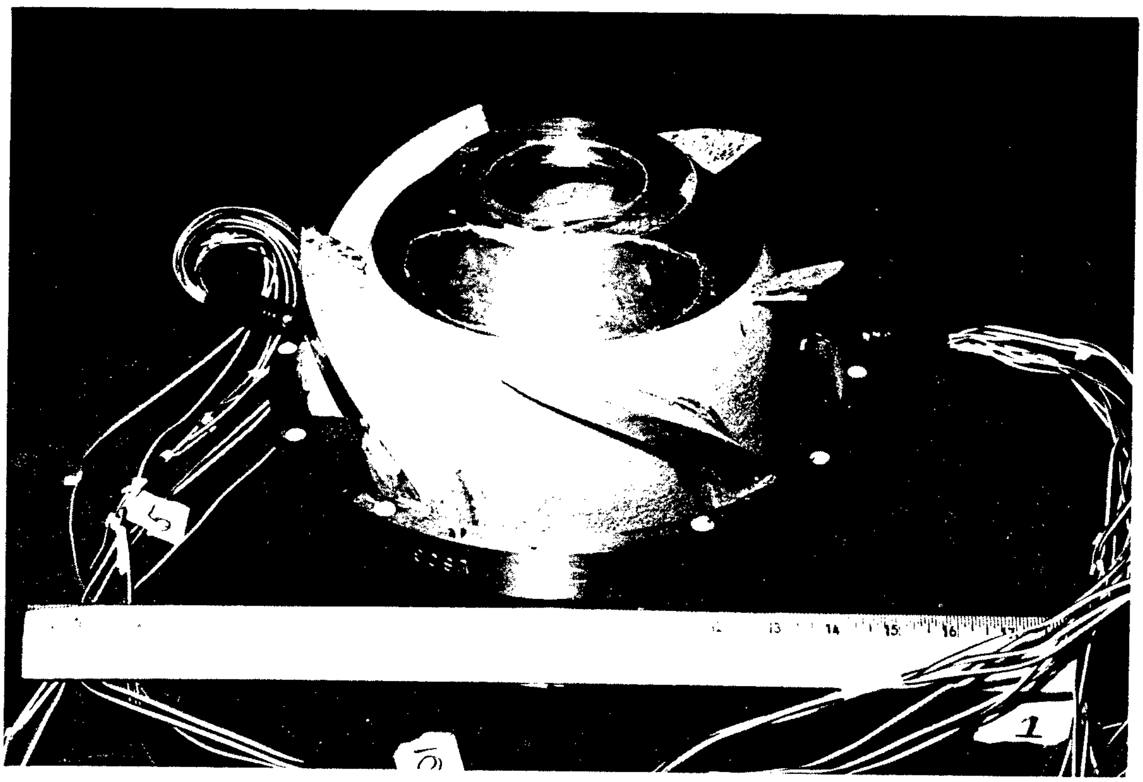

Fig. 31. Photograph of the pump bowl.

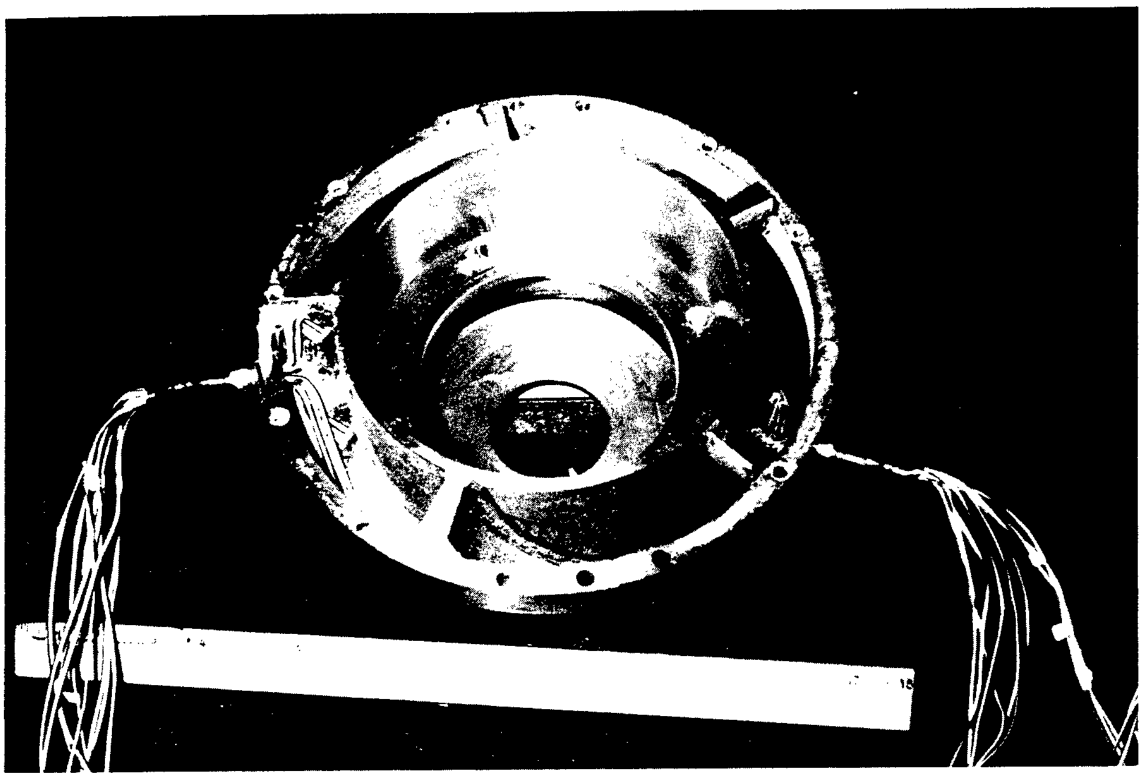

Fig. 32. Photograph of the pump bowl, alternate view.

Fig. 33. Photograph of the finished composite pump bowl.

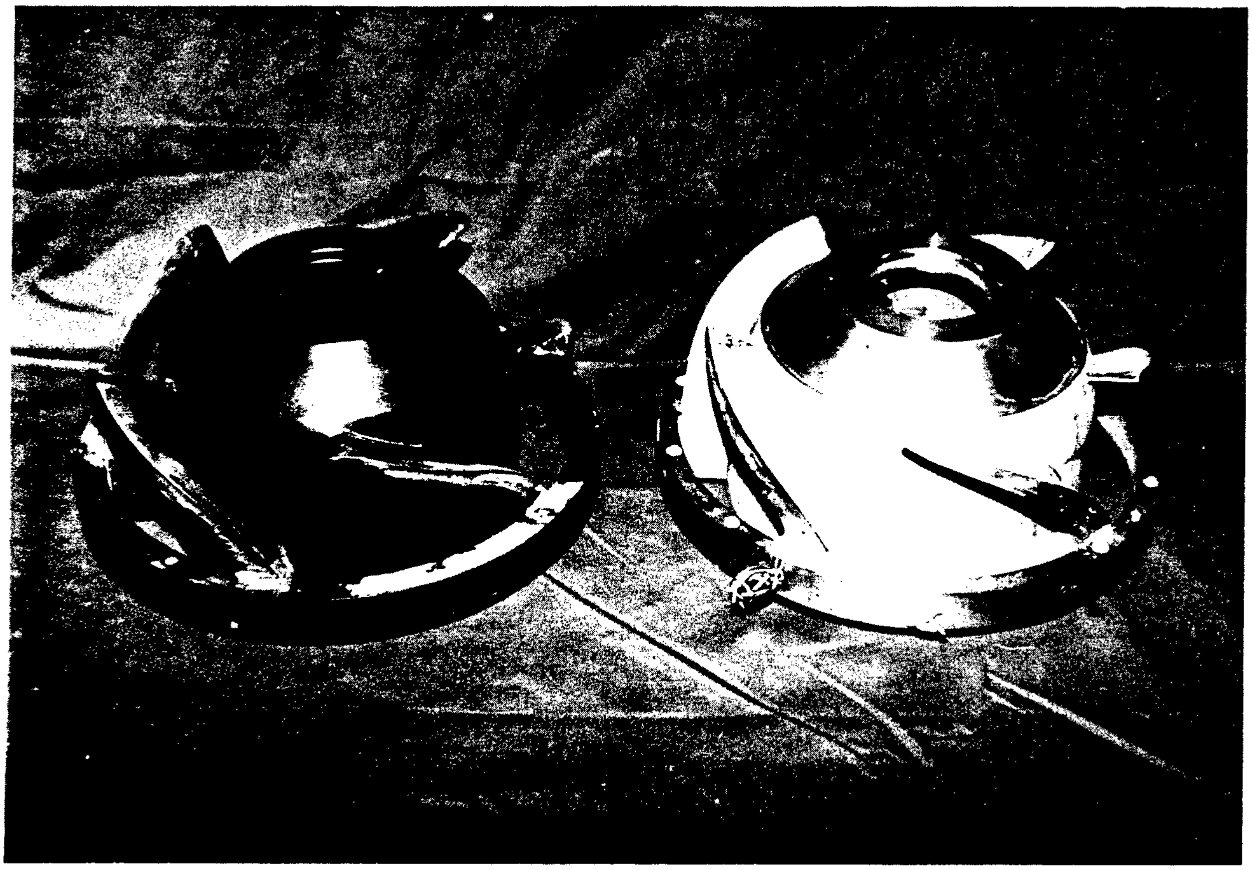

Fig. 34. Photograph of the finished composite pump bowl next to its metallic counterpart.

Fig. 35. Photograph of the assembled compositized CCN-150-5C.

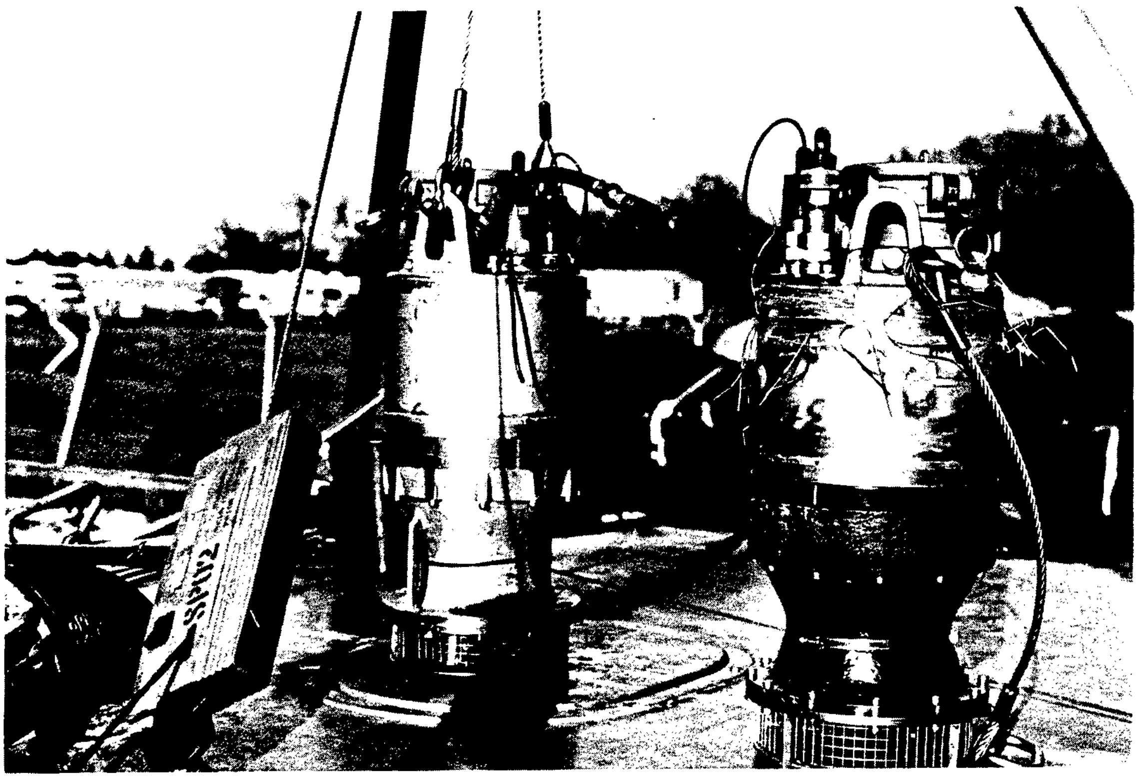

Fig. 36. Photograph of the assembled compositized CCN-150-5C next to its metallic counterpart.

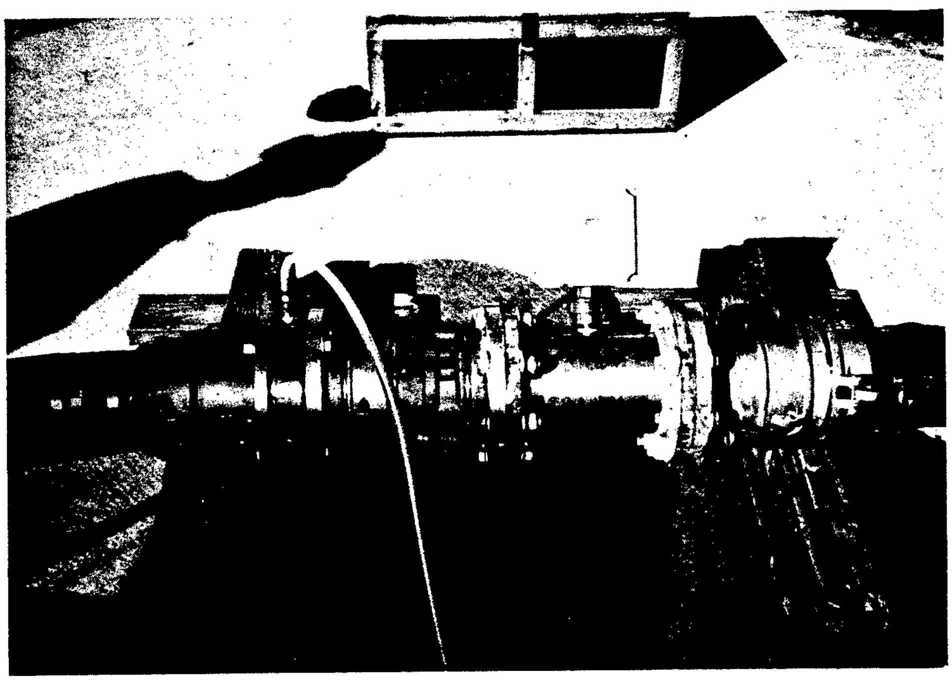

Fig. 37. Photograph of Blacett flow meter.

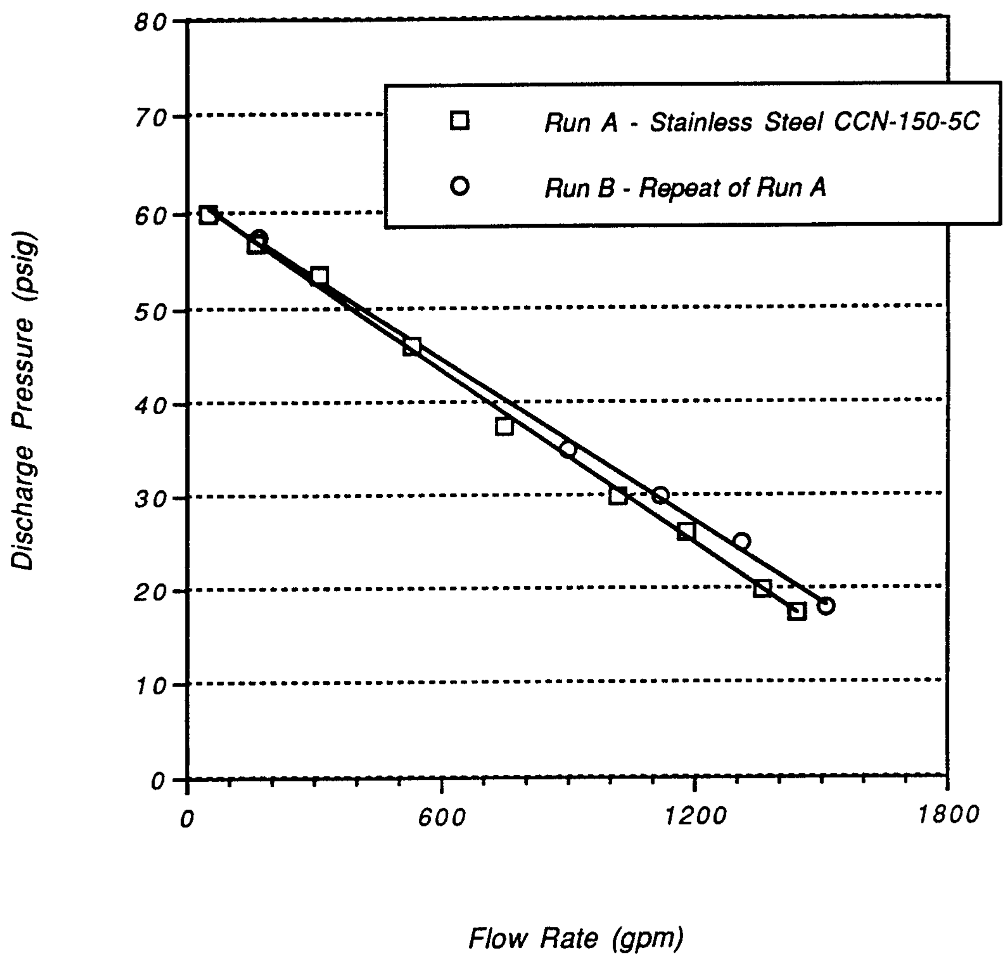

Fig. 38. Comparison of the discharge pressure versus flow rate for the baseline test and repeatability test, Runs A and B.

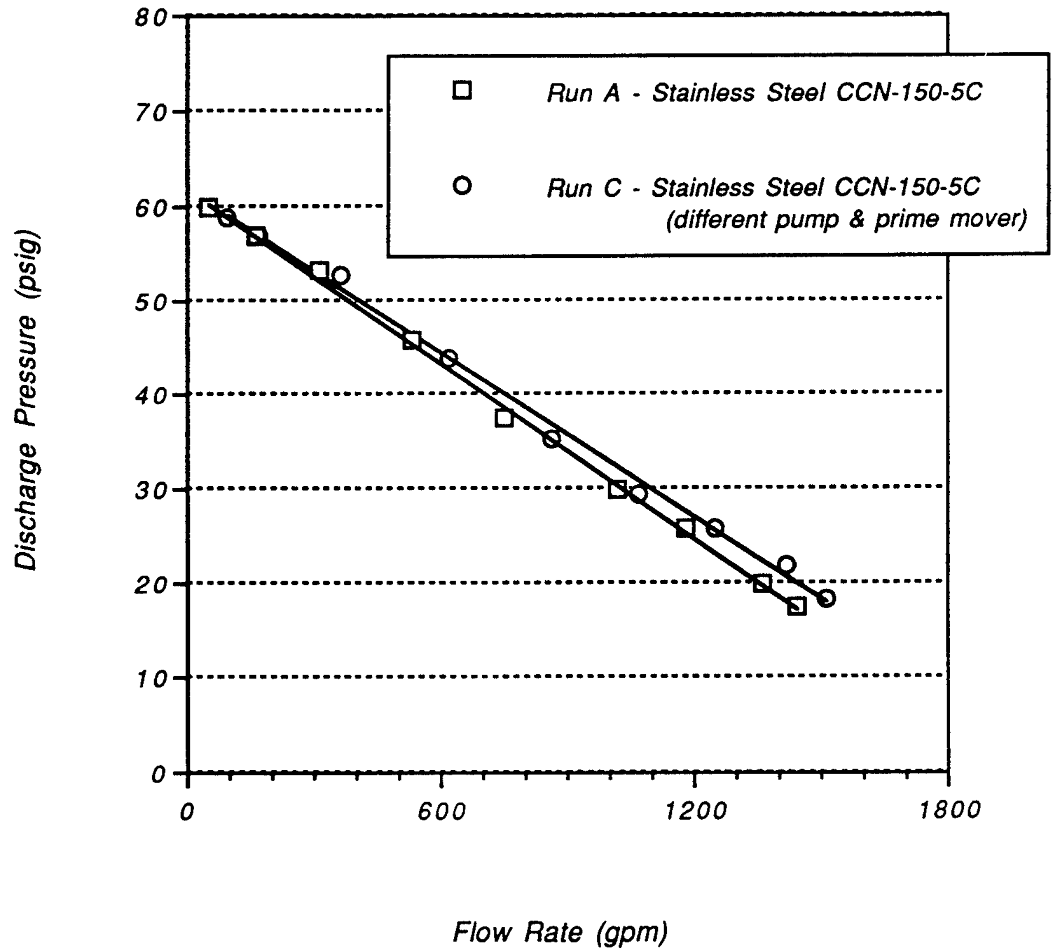

Fig. 39. Comparison of the discharge pressure versus flow rate for the baseline test and repeatability test, Runs A and C.

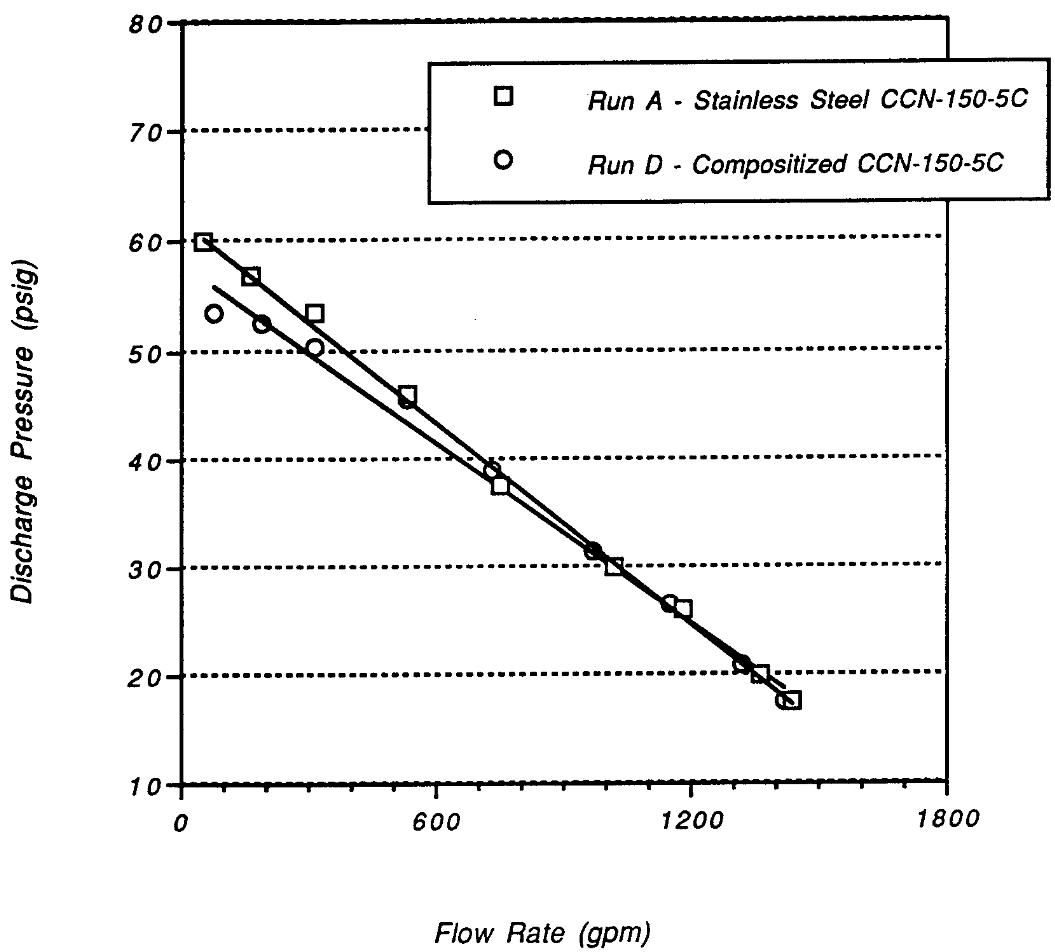

Fig. 40. Comparison of the discharge pressure versus flow rate for the baseline test and composite test, Runs A and D.